THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

DECEMBER, 1957

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Deformation of Metallic Surfaces by Abrasion and Polishing

L. E. SAMUELS: 'A Study of the Deformed Layer Produced on Metal Surfaces by Mechanical Machining, Abrasion and Polishing.'
Electroplating and Metal Finishing, 1957, vol. 10, Sept., pp. 279–82, 285; Oct., pp. 315–18, 343.

The aim of this article is two-fold: (1) to collate the results of experiments made on various materials, in order to obtain basic information on the nature of the surface deformation resulting from machining, abrading and polishing processes normally employed in preparation of metallographic specimens, and (2) utilizing the data secured by such collation, to propose a sequence of preparatory operations which will give the desired finish without inducing strain in the surface layers.

The first section is essentially a synopsis of observations which have been reported *in extenso* elsewhere, by the author and a co-investigator (see *Jnl. Iron and Steel Inst.*, 1957, vol. 186, pp. 211–18; *Nickel Bulletin*, 1957, vol. 30, No. 9, p. 176 (18–8 chromium-nickel steel); *Jnl. Inst. Metals*, 1956, vol. 85, pp. 51–62 (brass); *ibid.*, 1957, vol. 86, pp. 43–8 (zinc)).

The second part of the paper summarizes conditions which must be satisfied in order to meet, as nearly as possible, the theoretical ideal that each machining, abrading and polishing stage shall remove the deformation resulting from the previous stage and that the final treatment shall introduce no surface deformation at all. The recommendations made are along the same lines as those contained in the paper on stainless steel; see *Nickel Bulletin*, *loc.cit.*

It is concluded that a strain-free surface can be obtained by the following sequence: abrasion, rough polishing at a high cutting rate (which will completely remove the deformation caused by abrasion) and a finer stage of polishing, intended to provide the final surface condition. In material thus treated residual deformation is so slight that it will be removed by a standard metallographic etching treatment.

Electrolytic polishing after the initial abrading is effective only if the treatment is of sufficient duration to dissolve the deformed layer resulting from the abrasion operations. Residual strain can be reduced to a low level by the use of moderately long polishing times, but very long treatments (30 minutes or more) may be required to produce a completely strain-free surface.

NICKEL

Nickel-bearing Deposits in Ontario

J. E. THOMSON *et al.*: 'Copper, Nickel, Lead and Zinc Deposits in Ontario.' (Revised to Feb., 1957).
Ontario Dept. of Mines, Metal Resources Circular No. 2, 1957; 126 pp.

The report lists the deposits situated in each district of Ontario, with details of ownership, location, metals present, brief history of development, geology of the ores found, dimensions and grade. Where such information is available, statistics on production over various periods, and on ore reserves, are given. In many cases references to relevant published reports are included.

Reflectivity of Nickel

L. WARD: 'The Temperature Coefficient of Reflectivity of Nickel.'
Proc. Physical Soc., Sect. B, 1957, vol. 70, Sept. 1, pp. 862–6.

Variation, as a function of temperature, of the reflecting power of nickel was measured by a null method, at five wavelengths in the near infrared region of the spectrum. The results were found to be in satisfactory agreement with those calculated from previous work on emissivity. There was no conclusive evidence of a significant change in reflectivity at the Curie point of the metal.

Velocity of Sound in Nickel

J. F. W. BELL: 'The Velocity of Sound in Metals at High Temperatures.'
Philosophical Magazine, 8th Ser., 1957, vol. 2, Sept., pp. 1113–20.

The author describes a pulse method of measuring velocity of sound in thin rods, over a wide range of temperature. Results of measurements on aluminium, brass, nickel, iron, lead, solder and thallium show that, for metals in the strain-free condition, the method gives a sensitive indication of physical and structural changes.

The experiments were carried out on metals and alloys known to exhibit structural and other changes with variation in temperature, and in which, therefore, changes in elasticity and, hence, in velocity of sound transmission, could be expected. Changes associated with the onset of a liquid phase, the Curie point,

order-disorder and other changes are described. Results obtained on a specimen of high-purity nickel were in good agreement with related observations made by other investigators.

Titration of Nickel in the Presence of Cobalt

L. D. BRAKE, W. M. MCNABB and J. F. HAZEL: 'The Photometric Titration of Nickel in the Presence of Cobalt.'
Analytica Chimica Acta, 1957, vol. 17, Sept., pp. 314–17.

In the spectrophotometric titration of nickel in presence of cobalt, disodium ethylene diamine tetra-acetic acid is used as titrant. The end-point was obtained by plotting the corrected absorbancy against ml. of titrant added. Nickel concentrations of 2·5 to 25 mg. were determined in the presence of up to 8 mg. of cobalt, with an error of 1½ per cent., or less, depending upon the concentration of versenate used. The authors discuss the influence of pH, of nickel and cobalt and concentrations, the accuracy of the method, the effect of interfering elements, and the limitations of the procedure recommended.

Determination of Small Amounts of Nickel in Blood

M. L. CLUETT and J. H. YOE: 'Spectrophotometric Determination of Submicrogram Amounts of Nickel in Human Blood.'
Analytical Chemistry, 1957, vol. 29, Sept., pp. 1265–9.

The authors describe a method for determination of amounts as small as 0·1γ of nickel in human blood. The sample is wet-ashed with nitric acid and the mineral constituents are converted to chlorides by means of hydrochloric acid. Iron (III) and copper (II) interfere and are separated by ion exchange. Lead is also an interferant and is separated by 'adsorption' on calcium carbonate.

Nickel is determined by a spectrophotometric procedure based on the complex formed with diethyldithiocarbamate. The complex is extracted into isoamyl alcohol and the absorbance is measured at 325 μ in a 1-cm. cell. The gram-atom absorptivity is 37,000. The precision of the method is indicated by the average deviations of 0·005 and 0·009 p.p.m. of nickel obtained on synthetic blood-ash and whole-blood samples, respectively. Recoveries of added amounts of nickel were quantitative. It was found that the concentration of nickel in human blood varied between 0·025 and 0·067 p.p.m. The authors consider that the method described should be applicable also to analysis of mammalian tissues and products.

Preparation of Raney Nickel Catalysts

S. NISHIMURA and Y. URUSHIBARA: 'A Method for the Preparation of the Raney Nickel Catalyst with a Greater Activity.'
Bull. Chemical Soc., Japan, 1957, vol. 30, Mar., p. 199.

The authors report that greater activity can be obtained in Raney catalysts by adding the alkali (caustic soda) in portions, instead of the whole quantity being simultaneously added. A typical stepwise procedure is described, and the activity of catalysts so prepared is compared with that of catalysts made by the procedure recommended by ADKINS and BILLICA (*Jnl. Amer. Chemical Soc.*, 1948, vol. 70, p. 695).

Materials of Construction in the Chemical Industries: Nickel Catalysts

See abstract on p. 235.

Recovery of Nickel Catalyst for Fat Hardening

K. E. BHARUCHA, J. G. KANE and D. REBELLO: 'Recovery of Nickel from Spent Nickel Catalyst.'
Research and Industry, 1957, vol. 2, Aug., pp. 217–18.

Increasing attention has recently been given in India to methods for recovery of spent catalyst of the type used in fat hydrogenation. The four methods available have been critically examined: (1) incineration, (2) saponification, (3) solvent extraction of the fat, followed by treatment of the residue with mineral acids, and (4) digestion with mineral acids. Method (4) proved to be the most satisfactory, on account of ease of recovery of nickel from the spent catalyst and reclamation of the fat in an unchanged condition. It was found possible, in laboratory experiments, to recover over 90 per cent. of the nickel in a single digestion with inorganic acids when used in theoretical amounts, or with formic acid used in slight excess. Details of typical procedure are given in this paper, with analysis of the recovered nickel formate, and data on the activity of the regenerated catalyst.

Nickel in Uranium-Recovery Plant

See abstract on p. 231.

Diffusion of Nickel in Nickel Oxide

M. T. SHIM and W. J. MOORE: 'Diffusion of Nickel in Nickel Oxide.'
Jnl. Chemical Physics, 1957, vol. 26, Apr., pp. 802–4.

Diffusion coefficients for nickel in polycrystalline and monocrystalline nickel oxides were measured by the surface-activity method, at temperatures of 1000°–1400°C. in air. The observations made indicate that oxidation of nickel under comparable conditions of temperature and pressure proceeds via lattice diffusion of nickel through NiO.

Nickel Sulphate in Viniculture

O. K. DOBROLYUBSKII and A. V. SLAVVO: 'Use of the Trace Element Nickel for Nutrition of Grapes.'
Doklady Akad. Nauk S.S.S.R., 1957, vol. 112, pp. 347–9.
Chemical Abstracts, 1957, vol. 51, July 10, p. 9806.

An improved crop of grapes was achieved by the introduction of 0·05 g. of $NiSO_4$ per vine. Spraying of the vine with the sulphate solution proved effective

in increasing the quality of the grapes and their rate of growth, but if the trace element was added viâ the soil this improvement did not extend to the sugar and acid content. Addition of $NiSO_4$ tends to produce approximately equal amounts of sucrose and fructose in the final crop.

ELECTRODEPOSITION AND OTHER COATING METHODS

Automatic Electroplating in the Fiat Works

'New Fully Automatic Electroplating Machines for Fiat.'
Electroplating and Metal Finishing, 1957, vol. 10, Oct., p. 331.

The article gives details of two automatic electroplating machines, stated to be among the largest in Europe, to be installed by Electro-Chemical Engineering Company, Ltd., in the Turin plant of Fiat, S.p.A.

The machines are of the Efco-Udylite return type: the first (now undergoing final works tests) is specifically designed for cleaning and copper plating of automobile bumpers: the second (already being installed) will be used for bright-nickel- and chromium-plating of the bars after undercoating with copper. Operation is, in both cases, fully automatic and it will be possible to plate 160 bars per hour.

The sequence in the copper- and the nickel/chromium-plating stages are shown below:

Copper Plating

Anodic clean
180°–200°F. (80°–95°C.), 50 amp./sq. ft.; 5 min. 20 sec.

Rinse

Anodic clean
as above; 3 min. 50 sec.

Rinse twice

Acid dip
25–50 per cent. HCl

Rinse twice

Anodic clean
as above; 50 sec.

Rinse twice

Acid dip
10–25 per cent. HCl

Rinse twice

Cyanide copper strike
140°F. (60°C.), 40 amp./sq. ft.; 5 min. 20 sec.

Rinse twice

Acid dip
dilute sulphuric acid

Acid copper plate
65°–90°F. (20°–30°C.), 40 amp./sq. ft.; 32 min. 20 sec.

Rinse twice

Hot rinse
180°–200°F. (80°–95°C.)

Nickel/Chromium Plating

Emulsion clean
Efco emulsion cleaner; 130°F. (55°C.); 3 min. 50 sec.

Hot-spray rinse

Rinse

Cathodic clean
180°–200°F. (80°–95°C.), 50 amp./sq. ft.; 3 min. 50 sec.

Rinse

Anodic clean
180°–200°F. (80°–95°C.), 50 amp./sq. ft.

Rinse twice

Acid dip
5 to 10 per cent. sulphuric acid, air-agitated.

Rinse twice

Cyanide copper flash
140°F. (60°C.), 40 amp./sq. ft.

Rinse twice

Nickel plate
Efco-Udylite solution, 140°F. (60°C.)
40 amp./sq. ft.; 32 min. 20 sec.

Drag-out reclaim

Rinse

Warm rinse
160°F. (70°C.)

Chromium plate
56 oz./gl. CrO_3, 100°F. (40°C.), 120 amp./sq. ft.; 6 min. 50 sec.

Drag-out reclaim

Rinse twice

Neutralize

Cold rinse

Hot rinse

Cold-air blow-off
3 min. 50 sec.

Semi-Automatic Plating Plant at Hoover, Ltd.

'The New Semi-Automatic Plating Shop at Hoover's High Wycombe Works.'
Metal Finishing Jnl., 1957, vol. 34, Oct., pp. 396–7.

The article gives a brief résumé of the facilities available in the new plant used in the plating steel covers of the firm's range of steam-or-dry irons.

Plating is carried out on a flow-line production system, the main feature of which is an automatic electroplating circuit. This consists of a central carrier operating above and between a double line of tanks. The hanger-arms which carry the workpieces are made in the form of a bell crank, and are mounted pivotally on small roller carriages which move along a guide rail.

After being degreased, the component to be plated is loaded onto the central conveyor and, in turn, passes automatically through cathodic-cleaning, cold-water rinsing, anodic-cleaning, cold-water rinsing, acid-etching, cold-water rinsing, copper-striking, and two cold-water rinsing treatments. The work

is then transferred manually to a semi-automatic tank, where 0·0007 in. of copper is deposited. It then successively enters a dry-out solution, a cold-water and a hot-water rinse, and, after drying and polishing, is again placed on the automatic conveyor which, on this second round, modifies the circuit by immersing the part in a nickel-plating, instead of a copper-plating, solution. Treatment in the nickel electrolyte is for 16 minutes, resulting in the deposition of 0·0008 in. of nickel. After suitable rinsing the work makes a final round on the automatic conveyor, during which chromium plating and necessary ancillary operations are carried out.

The article also contains notes on the architectural lay-out of the shop.

Nickel Plating for Rebuilding of Worn Parts

E. CALDERON: 'Stress-Free Nickel Plate: Some Notes on Experience with the Sulphamate Bath in the U.S.A.'
Metal Finishing Jnl., 1957, vol. 3, Sept., pp. 373–4.
See also Steel, 1957, vol. 1 41 Sept. 30, pp. 78, 80–2.

This short article gives details of a nickel-sulphamate solution developed by Ryan Aeronautical Company, for salvage plating of power-plant components of high-alloy materials, e.g., stainless steel, Inconel X and A-286 alloy. The composition of the electrolyte used and the operating conditions are as shown below.

	oz./gal.
Nickel sulphamate	60
Nickel-metal equivalent	12·2
Boric acid	4
Wetting Agent	0·05

pH	3·0–4·5
Temperature	100°–140°F. (37°–60°C.)
Density	29°–31° Baumé
Agitation	Movement of cathode bar and/or circulation of solution.
Anode efficiency	100%
Cathode efficiency	98–100%

Deposits obtained from this solution are stated to be smooth and ductile, showing the slight sheen characteristic of fine-grained high-purity nickel, and having a tensile strength of the order of 60,000 p.s.i. (nearly 27 tons per sq. in.) or greater, according to the conditions of deposition. Hardness can be controlled within the range 200–500 V.P.N., and ductility, as measured by percentage elongation, varies from 30 to 6 per cent., in relation to the hardness.

The sulphamate solution has been found to be particularly suitable for re-building of worn parts because the deposits made from it are free from the tensile stress present in coatings produced from the Watts-type or chloride solutions, and hence are not liable to peel, crack or warp, and do not lower the fatigue strength of the basis metal. It is further claimed that the nickel-sulphamate bath, in addition to its ability to produce deposits having compressive stress, also exhibits exceptional levelling power. The degree of compressive stress in the deposit, the hardness of the coating, and the throwing power of the solution, all increase with increase in pH: emphasis is therefore laid on the necessity for close control of that variable. The pH may be lowered by addition of sulphamic acid and raised by nickel carbonate. Temperature must also be controlled since, within the working limits indicated, the hardness of the deposits falls with rising temperature.

The article also briefly reviews the properties of sulphamic acid and its metal salts, and lists the improved properties possessed by the coatings deposited from the sulphamate bath.

Influence of Impurities on Mode of Growth of Nickel Deposits

B. C. BANERJEE and A. GOSWAMI: 'Influence of Impurities on the Structure of Electrodeposited Nickel.'
Jnl. Scientific and Industrial Research, India, Sect. B, 1957, vol. 16, Apr., pp. 144–8.

As a sequel to observation of change in crystal growth resulting from the presence of small amounts of aluminium sulphate in nickel-plating solutions, a systematic study was made of the effect of the following impurities: sulphates of chromium, aluminium, iron and magnesium; potassium alum; chromic acid; glycine; L-aspartic acid; L-glutamic acid; gelatin.

The results of electron-diffraction examination of the deposits (recorded individually in this paper) show that the mode of crystal growth is profoundly affected by the presence of many of these contaminants, especially when the solution is in the pH region in which formation of colloidal compounds is facilitated. Particular attention is directed to the deleterious influence of chromic acid, and the significance of this effect in relation to industrial nickel/chromium plating is emphasized.

See also

A. GOSWAMI: 'Effect of Addition Agents on the Plating of Nickel', *ibid.*, pp. 315–17.

Report of experiments in which the effect of some twenty addition agents was studied on deposits made from two varieties of Watts-type nickel solution of pH favourable to lateral growth of the crystals of the deposit. It was observed that addition agents producing high cathodic polarization cause outward-growing crystals.

Influence of Composition on Behaviour of Nickel Anodes

I. L. ROGELBERG and E. S. SHPICHINETSKII: 'The Chemical Composition of Depassivated Anode Nickel.'
Tsvetnye Metally, 1956, vol. 29, No. 8, pp. 68–70.
Chemical Abstracts, 1957, vol. 51, July 25, p. 10,273.

'Experiments were carried out to examine the hypothesis that C and O_2 were responsible for the depassivation of Ni anodes during electrolytic refining. Anodes containing O_2 and C separately in amounts from 0·05 to 0·5 per cent. O_2 and 0·1 to 0·25 per cent. C were made by using 99·99 per cent. pure Ni. A Ni_2SO_4-$NiCl_2$ bath was used for the electrolysis.

Sufficient boric acid was added to maintain a pH of 5·0 to 5·8. It was found that, contrary to the previous data in the literature, C and O_2 had no effect on passivation. Similarly the addition of Si, Al, Cu, Mn, Mg, Ti, Fe or Zn had no effect. It was found that 0·002 to 0·01 per cent. S did depassivate the anodes satisfactorily. The previous results in the published literature are explained as being attributable to S present in the anodes. It is suggested that the mechanism of the effect of S is related to the formation of microgalvanic cells between Ni and Ni_3S_2. In practice it would be necessary to control the S content to be high enough for depassivation (>0·002 per cent.) and low enough to ensure workability (<0·01 per cent.).'

Electroless Nickel Plating: S.A.E. Specification

SOC. AUTOMOTIVE ENGINEERS: 'Electroless Nickel Plating.'
A.M.S. Specification 2404, Sept. 15, 1957: 2 pp.

The specification covers a type of coating 'primarily intended to provide hard, ductile, wear-resistant and corrosion-resistant surfaces for operation at moderate temperatures (up to 1000°F.; 540°C.) and to provide uniform build-up on complex shapes'. Requirements with regard to preparation include specification of the condition of the surface immediately prior to plating. Plating is to be performed 'by chemical deposition of an amorphous high-nickel low-phosphorus metallic compound on the surface from a chemical nickel bath'. Details of post-plating heat-treatment are also given.

For testing the quality of the plated material the following provision is made:
'Steel strip specimens approximately $\frac{1}{32} \times 1 \times 4$ in., when cleaned, plated, and heat-treated simultaneously with parts, shall withstand rapid bending at room temperature through an angle of 180° around a diameter equal to the thickness of the specimen, without showing separation of the plate from the basis metal when examined at approximately 4 diameters magnification. The formation of cracks which do not result in flaking or blistering of the plate shall not be considered as basis for rejection. As a referee test, plate shall show no blisters or cracks on steel parts or test panels representing parts, after being heated in air, preferably in a circulating air furnace, at 700°F. ±10° for 23 hours, followed by heating at 1000°F. ±10° for 1 hour.' A salt-spray corrosion test is also specified.

Corrosion Fatigue of Plated Steel

See abstract on p. 233.

Electrodeposition of Tin-Nickel Alloys from Pyrophosphate Solutions

J. VAID and T. L. R. CHAR: 'Electrodeposition of Tin Alloys from the Pyrophosphate Bath.'
Jnl. Scientific and Industrial Research, India, Sect.A, 1957, vol. 16, No. 7, pp. 324–5.

Report of studies (in the Department of General Chemistry, Indian Institute of Science, Bangalore) on the co-deposition of tin with copper, zinc, nickel or lead. The work covered investigation of the conditions necessary for co-deposition over various ranges of composition; the effects of operating variables on composition of the plate and on efficiency; cathode potentials, and the structure of the alloy deposits. The results show that it is possible to deposit, from pyrophosphate solutions, satisfactory alloys over ranges of composition which include alloys recognized as of industrial importance, e.g., 55 and 90 per cent. Cu copper-tin, 80 per cent. Sn tin-lead, 65 per cent. Sn tin-nickel and 10 and 50 per cent. Sn tin-lead. A table shows optimum conditions for electrodeposition of the respective types of alloy; those recommended for deposition of tin-nickel alloys are as follows:—

		g./L.
Stannous pyrophosphate		20
Nickel chloride		24
Potassium pyrophosphate (anhyd.)		231
Ammonium citrate		10
pH	8·5	
Sp. resistivity, ohms/cu. cm.	4·2	
Temp., °C.	60	
Bath voltage, V.	2·2–2·8	
Cathode	Pt, Cu, or brass	
Anode	Stainless steel	
Cathode c.d., amp./sq. ft.	5–58	
Deposit composition % Sn	67–92	
Cathode efficiency, %	64–91	

Spectrophotometric Determination of Nickel in Plating Solutions

N. F. DOHERTY: 'Spectrophotometric Determination of Nickel in Bright Cadmium and Bright Gold Plating Solutions.'
Plating, 1957, vol. 44, Sept., pp. 971–4.

The author describes procedure involving the use of an instrument known as the Bausch and Lomb Spectronic 20 colorimeter. When using this technique, analysis depends first on the standard method of developing a coloured soluble complex of nickel with dimethylglyoxime. The instrument then analyses a sample of the complex by subjecting it to light of specified wavelengths. The degree of light transmittance is registered on a double scale, on which readings can be taken in terms of either transmittance or optical density. The effective range of the instrument is the near ultra-violet to the near infrared.

This paper gives detailed instructions for analysis of nickel in cyanide-gold, and cyanide-cadmium electrolytes and for determination of the amount of primary brightener in the Harshaw modified XXX bright-nickel solution.

Copper Sulphate for Electroplating

BRIT. STANDARDS INSTN.: 'Copper Sulphate for Electroplating.'
B.S. 2867: 1957; 11 pp. Price 3/-.

This specification is one of a series prepared under the aegis of the Chemical Engineering Industry

Standards Committee of the Institution, for anodes, salts and other materials required in electroplating.

It is specified that the copper sulphate shall be in the form of blue crystals and shall correspond approximately in composition to $CuSO_4.5H_2O$; also that the material shall be free from extraneous matter, particularly chromates, nitrates and organic compounds. It is required to contain not less than 24·9 per cent. of copper (as determined by a method of analysis laid down in an appendix to the specification) and maximum limits are specified for the following impurities: nickel, iron, arsenic, insoluble matter, chlorides. Appendices give details of analytical procedure approved for estimation of these impurities.

NON-FERROUS ALLOYS

Production of Nickel Alloys at Wiggin Zenith Works, Glasgow

A. B. GRAHAM: 'Nickel and Nickel Alloys.'
Metal Industry, 1957, vol. 91, Sept. 27. pp. 275–8.

Condensed historical review, covering events from the early 1920's, when Messrs. G. and J. Weir were appointed by The International Nickel Company to deal with development of Monel in the U.K., through the subsequent expansion of activities under Messrs. Henry Wiggin and Company (acting in association with INCO and Mond), to the activities of the present day.

The nature of the work at Zenith has materially changed since the plant was erected in 1928. The alloys handled have increased in number from two or three to approximately forty, and there has been much expansion in the type of product made. In addition to tubing, a wide range of sections and forgings for jet engines is now in regular production: in particular there has been intensive development of facilities for meeting the requirements of users of the Nimonic alloys. Such widening of activities has necessitated modification of existing equipment and introduction of many new types, in order to deal adequately with the specialized nature of the materials handled. Some of the changes which have thus been made are described in this article, as exemplified, *inter alia*, by novel methods of extrusion, including the use of the glass-lubrication process developed by Séjournet. This has made possible extrusion ratios of as much as 60 to 1, compared with the maximum of 20 to 1 possible with the normal graphitic-base lubricants formerly employed.

Since a large proportion of the material produced at Zenith is cold-rolled or cold-drawn after extrusion, bright annealing is of considerable importance: the article includes notes on the furnaces and operating technique which have been developed to ensure maintenance of the surface of the annealed material in a condition suitable for cold working. In describing heat-treatment, attention is called to special procedures required for the Nimonic high-temperature alloys, which, in the form of forgings, extrusions or extruded-and-rolled section, are the most important product of the Zenith works. The applications of these alloys are briefly reviewed and particular reference is made to development work on their use in new designs of cooled turbine blades. In this connexion a résumé is made of the technique developed by Henry Wiggin and Company for production of the holes by means of which the blades are cooled.

The article ends with notes on various types of ancillary equipment in the works, methods adopted for handling scrap, etc. Attention is directed also to the wide range of social and welfare amenities available to the staff.

Intergranular Oxidation in Nickel-base Alloys

See abstract on p. 229.

Electrical Characteristics of Evanohm Resistance Alloy

See abstract on p. 229.

Corrosion of Nickel-containing Aluminium Alloys in High-Temperature Water

See abstract on p. 231.

Resistance of Materials to Corrosion by Formaldehyde

See abstract on p. 233.

Magnetizability of Nickel Alloys near the Curie Point

See abstract on p. 222.

Bearing Characteristics of Nickel-base Alloys

R. K. KOZLIK: 'Bearing Characteristics of Nickel-base Alloys.'
Machine Design, 1957, vol. 29, Aug. 22, pp. 139–40 and 142.

The article (an abridgement of a paper to the American Society of Lubrication Engineers) reviews, in general terms, the bearing characteristics of various wrought and cast nickel-base alloys. The hardness and approximate compositions of the alloys discussed are shown in Table I on page 220. Evaluation of their bearing characteristics is based on results of a series of wear and galling tests, in which the alloys were mated with themselves and with each other.

The paper was divided into four main parts. The first briefly reviewed the bearing characteristics, when self-mated, of the principal wrought nickel alloys (A Nickel, Monel and Inconel), their age-hardenable counterparts (Duranickel, K Monel and Inconel X), and the cast versions of the respective materials (G Nickel, S Nickel, H Monel and S Monel, and S Inconel). The bearing applications of the wrought alloys are stated to be limited, but the cast alloys show greater resistance to wear and galling, due mainly to their higher silicon and carbon contents. Silicon, in particular, is important, since its presence

Table 1
Hardness and Approximate Composition of Wrought Nickel-base Alloys
(*see abstract on p. 219*)

Alloy	Composition								Brinell Hardness
	Ni %	Cu %	Cr %	Fe %	Si %	Mn %	C %	Other Elements	
A Nickel	99·6	—	—	0·05	0·02	0·25	0·07	—	196—Cold-drawn
Duranickel	93·8	—	—	0·12	0·58	0·38	0·20	Al 4·5, Ti 0·4	235—Cold-drawn
Monel	66·0	31·2	—	1·41	0·14	1·05	0·19	—	235—Cold-drawn
K Monel	65·5	29·1	—	0·96	0·12	0·60	0·15	Al 3·0, Ti 0·5	340—Aged
Inconel	78·5	—	14·5	6·40	0·20	0·23	0·07	—	262—Cold-drawn
Inconel X	72·9	—	15·0	6·77	0·42	0·59	0·04	Al 0·9, Ti 2·4, Nb 1·0	340—Aged
17–7 P.H. Stainless ..	6·7	—	17·2	Bal.	0·36	0·64	0·07	Al 1·0, P 0·02	436—Hardened
304 Stainless ..	9·1	—	18·3	Bal.	0·67	0·65	0·07	—	180—Annealed
G Nickel	94·2	—	—	0·5	1·5	0·80	1·5	—	131
S Nickel	90·0	—	—	2·0	6·0	0·78	0·68	—	241
H Monel	63·0	30·5	—	1·5	3·2	0·80	0·10	—	215
S Monel	63·0	29·5	—	2·0	4·0	0·80	0·08	—	364
Inconel	71·5	—	16·0	8·0	2·0	1·0	0·20	—	166
S Inconel	70·8	—	15·2	7·0	5·4	1·3	0·21	—	277
Colmonoy 6	65-75	—	13-25	—	*	—	*	B 2·7—4·7	—
Waukesha 23 ..	78	—	—	—	—	2·0	—	Sn 8, Pb 4, Zn 8	179
Waukesha 50 ..	60	—	12·5	14·0	0·75	0·75	—	Sn 6, Mo 3, Bi 3	161
Waukesha 88 ..	Bal.	—	12·0	—	0·20	0·80	—	Sn 4, Mo 3, Bi 3·5	127
Leaded Bronze ..	0·46	79·9	—	—	—	—	—	Sn 6·3, Pb 10·1, Zn 2·1	69
Neveroil 21†	32·3	64·5	—	*	—	—	*	Sn present	17

† Pressed and sintered product. * Present.

Table II
Guide to Expected Performance of Lubricated Nickel-Alloy Combinations*

(*see abstract on p. 219*)

	A Nickel	Duranickel	Monel	K Monel	Inconel	Inconel X	17–7 PH	304 Stainless	G Nickel	S Nickel	H Monel	S Monel	Cast Inconel	S Inconel	Colmonoy 6	Waukesha 23	Waukesha 50	Waukesha 88	Leaded Bronze	Neveroil 21	Hard Cr Plate	Molybdenum-Disulfide Coat	Sulfurization Coat
A Nickel	P																						
Duranickel	P	F																					
Monel	P	P	P																				
K Monel	P	F	P	F																			
Inconel	P	P	P	P	P																		
Inconel X	P	F	P	F	P	F																	
17–7 PH	P	P	P	P	P	P	P																
304 Stainless	P	P	P	P	P	P	P	P															
G Nickel	P	G	F	F	F	F	P	P	G														
S Nickel	P	G	F	F	F	G	P	P	F	G													
H Monel	P	F	F	F	P	F	P	P	F	F	F												
S Monel	P	G	F	F	F	G	P	P	F	G	F	G											
Cast Inconel	P	P	P	P	P	P	P	P	F	F	P	F	F										
S Inconel	P	G	F	F	F	G	P	P	F	G	F	G	F	G									
Colmonoy 6	P	G	F	F	F	G	P	P	F	G	F	G	F	G	G								
Waukesha 23 ..	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G							
Waukesha 50 ..	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G						
Waukesha 88 ..	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G					
Leaded Bronze ..	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G				
Neveroil 21	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G			
Hard Cr Plate ..	P	P	F	F	P	P	P	P	F	P	P	P	P	P	P	G	G	G	G	G	P		
Molybdenum-Disulfide Coat	F	F	F	F	F	F	F	F	F	P	P	P	F	P	P	G	G	G	G	G	F	G	
Sulfurization Coat ..	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G

* G=Good, F=Fair, P=Poor.

results in the formation of hard, free silicides which eliminate wear and galling: this is an especially significant feature in cast Inconel.

The second section of the paper comprised a résumé of the bearing characteristics of dissimilar combinations incorporating some of the nickel alloys, and discussed combinations most suitable for certain specific conditions. It is found that hardness is no criterion of wearing performance, nor does the mating of an alloy containing hard micro-constituents with a material of poor wear-resistance necessarily produce good results.

When selecting the type of bearing alloy for any specific application, compressive yield strength is a factor which must be taken into account. This aspect is emphasized in the third section (which deals with nickel-base alloys mated with soft bearing materials), and is illustrated by reference to tests on wrought nickel alloys running against a leaded copper-tin bearing bronze.

Finally, the efficacy of protective coatings is discussed. Brief reference is made to the use of electrodeposited hard chromium and molybdenum-disulphide coatings, and to the improvement in anti-galling properties shown by surfaces of stainless steel which have been subjected to a fused-salt sulphurization treatment.

Table II on page 221 summarizes the bearing performance which may be expected from nickel-base alloys used in various combinations.

Deformation of Metallic Surfaces by Abrasion and Polishing

See abstract on p. 214.

Inconel in the Paper-Making Industry

See abstract on p. 235.

Nickel-containing Materials in Avon Aircraft Gas Turbines

See abstract on p. 228.

Galvanic Corrosion in Water Meters Incorporating Nickel Alloys

See abstract on p. 234.

Nickel-containing Materials in Uranium-Recovery Plant

See abstract on p. 231.

Materials for Ducts and Hoods of Exhaust Systems

See abstract on p. 237.

Materials of Construction in the Chemical and Chemical-Engineering Industries

See abstract on p. 235.

NICKEL-IRON ALLOYS

Heat-Treatment of Nickel-Alloy Magnets

A. G. CLEGG and M. McCAIG: 'Processes Occurring during Heat-Treatment of Alcomax.'
Proc. Physical Soc., Sect. B, 1957, vol. 70, Sept. 1, pp. 817–22.

The authors introduce their paper by brief notes on the essential features of the processes by which anisotropic magnets of the Alcomax, Ticonal or Alnico V types are produced. The anisotropy can be produced without causing very high coercivity in the alloy, and this paper is concerned mainly with the processes by which high coercivity can be ensured. The alloy Alcomax was studied in conditions resulting from two different heat-treatments, involving two techniques. Curves of saturation intensity *vs.* temperature were obtained by means of a Sucksmith balance, and curves of coercivity *vs.* temperature by extraction from a solenoid. It is concluded that maxima observed in the coercivity curves are associated with subsidiary Curie points. Reversible changes in room-temperature coercivity produced by treatment at temperatures between 600° and 700°C. are also associated with the appearance and disappearance of subsidiary Curie points.

See also following abstract

M. McCAIG: 'The Unusual Magnetic Properties of Quenched Alcomax III', *ibid.*, pp. 823–6.

Alcomax III is an alloy of the nominal composition cobalt 24, nickel 13·5, aluminium 8·0, copper 3, niobium 0·8, per cent., balance iron. It is made into an anisotropic permanent-magnet alloy by cooling at a controlled speed in a magnetic field, applied in the direction along which the material is afterwards to be magnetized, and this treatment is followed by prolonged tempering at about 600°C. It has, however, been observed that if such an alloy is quenched from a high temperature properties very different from those of the permanent-magnet type can be produced, and it is shown in this paper that quenching from a high temperature produces in Alcomax III the characteristics of a rather unusual soft magnetic material. Permeability is almost constant up to flux densities of more than 5,000 gauss., and the ratio of remanence to saturation intensity is less than 0·1. Some details of typical properties resulting from such treatment are given and their theoretical implications are discussed.

Magnetizability of Nickel Alloys near the Curie Point

K. BELOV and Y. PACHES: 'Spontaneous Magnetizability of Alloys near the Curie Point.'
Fizika Metallov i Metallovedenie., 1957, vol. 4, pp. 48–53.

It is pointed out that the magnetizability of metallic materials does not terminate suddenly at the Curie point, but that it vanishes gradually, forming a 'tail' to the main magnetizability/temperature curve.

This paper describes investigation of the shape of these 'tails' as observed in binary nickel alloys containing, respectively, 3·1 per cent. of silicon, 2·5 per cent. of manganese or 62 per cent. of iron. For summary of the conclusions drawn, see *Chemical Abstracts*, 1957, vol. 51, Aug. 25, p. 11,962.

Nernst Effect in Nickel-Iron Alloys

E. P. SVIRINA and R. P. IVANOVA: 'The Nernst Thermo-Magnetic Effect in Iron-Nickel Alloys.'
Fizika Metallov i Metallovedenie, 1956, vol. 3, pp. 444–8.

The Nernst e.m.f. (E) was measured as a function of composition and of applied field, for seven alloys of the nickel-iron system, containing, respectively, 28, 30, 36, 45, 65, 75 and 85 at. per cent. nickel. For summary of observations made see *Metallurgical Abstracts*, 1957, vol. 24, Aug., p. 949.

Nickel-Iron Alloys having Special Physical Properties

C. GORDON SMITH: 'Nickel Alloys with Special Physical Properties.'
Jnl. Birmingham Metallurgical Soc., 1957, vol. 37, Sept., pp. 553–65.

Full form of the paper delivered to the Society, Feb. 28, 1957, and abstracted in *Nickel Bulletin*, 1957, vol. 30, No. 11, p. 200.

Materials of Construction in the Chemical and Chemical-Engineering Industries

See abstract on p. 235.

Production and Properties of Nickel-containing Ferrites

H. KEDESDY and A. TAUBER: 'Synthesis of Some Ferrites.'
Jnl. of Metals, 1957, vol. 9, Sept.: *Trans. Amer. Inst. Mining and Metallurgical Engineers*, vol. 209, pp. 1140–8.

This paper reports experiments on the synthesis of some ferrites (sintered metallic oxides of spinel-structure type) which are of interest as magnetic materials.

The general formula for ferrites is $MeFe_2O_4$, where Me is a divalent metal ion such as Ni, Zn, Mg, Mn, Cu, Cd and Fe. Only two of these ferrites are non-ferromagnetic, those containing zinc and cadmium. Solid solutions can be formed between different ferrites, and it has been found that solid solutions of a ferromagnetic ferrite with a non-ferromagnetic type yield much better magnetic properties than are shown by the basic ferrite body. During the past 20 years the synthesis of ferromagnetic oxides has been the subject of extensive research, with particular reference to methods of production and processing which will give optimum properties in the materials when made under commercial large-scale conditions.

Production of a ferrite material usually comprises intimate mixing of the constituent oxides, pressing, and firing at temperatures above 1,000°C. This paper records results of a systematic investigation of the influence of production conditions on a Ni-ferrite, a mixed NiZn-ferrite and a ferrite involving a complex formation process, Mn-ferrite. Trends in magnetic characteristics of the three materials are related to variations in firing cycle and furnace atmosphere.

It is shown that the beginning of ferrite formation, as observed by X-ray diffraction, occurs at temperatures below 1000°C., and after firing at 1250°C. the reaction is complete. Firing at 1250°C. does not, however, give optimum properties: temperatures up to 1400°C. (for the Ni-, and NiZn-ferrites) and 1450°C. or slightly higher (Mn-ferrite), under the most favourable conditions, are required to obtain ferrites having the best possible properties. The air-fired cooling cycle was found to give the best results for the Ni- and NiZn-ferrites. A table summarizes magnetic data for ferrites prepared under optimum conditions, using four firing temperatures (1200°, 1300°, 1400° and 1450°C.). The experiments showed that furnace atmosphere can influence the magnetic properties of all the ferrites examined.

In connexion with nickel-containing ferrites, *see also*

G. CAMPBELL: 'Some New Electric and Magnetic Ceramics.'
Jnl. Scientific Instruments, 1957, vol. 34, Sept., pp. 337–48.

This paper reviews the nature, properties and applications of four classes of 'ceramics' which are of interest to the engineer and physicist on account of their electrical and magnetic properties. The four groups to which consideration is given cover, respectively, insulator, conductor, ferroelectric and ferromagnetic types. In the fourth group, particular attention is given to nickel-containing ferrites.

CONSTRUCTIONAL STEELS

Constitution, Structure and Properties of Steel

E. GREGORY and E. N. SIMONS: 'The Structure of Steel.'
Second Edn. published by *Odhams Press Ltd., London*, 1957: 176 pp. Price 18/-.

This book, the first edition of which was published in 1938, is intended to give a simple, and as far as possible, non-technical explanation of the constitution, structure and properties of carbon and alloy steels. It is written to meet the preliminary needs of students, and of engineers and buyers of steels. The text of the new edition has been extended to incorporate information on some recent developments in steel metallurgy.

The opening chapters outline the basis constitution of iron and steel and deal briefly with phase transformations, structure, and the nature and effect of impurities.

Crystal structure is also considered. A condensed review is made of the range of low-alloy steels commercially produced, and the structural forms characteristic of such steels are described and illustrated. A chapter is allocated to stainless and heat-resisting steels, with particular reference to austenitic chromium-nickel grades, the properties of which are tabulated and discussed.

A major section of the book is devoted to a condensed survey of the various mechanical and non-destructive test techniques which are in current use. Heat-treatments are dealt with from the standpoint of their effects on the properties of the steels, and the book ends with a chapter on changes in structure which result from mechanical working.

Two useful appendices contain, respectively, a correlation of Brinell hardness with tensile strength, and a glossary of terms, which will prove useful to the readers for whom the book is intended.

Boron, Titanium and Zirconium in Nickel-Chromium-Molybdenum Steels

S. J. ROSENBERG: 'Temper Brittleness of Boron-Treated Steel.'
Wright Air Development Center Tech. Report 56-396, Dec. 1956; 58 pp. *P.B.* 121889.

The investigation described in this report is supplementary to earlier work done by the author in collaboration with J. D. GRIMSLEY (see *Jnl. Iron and Steel Inst.*, 1957, vol. 182, Mar., pp. 278-92). The earlier investigation indicated that boron, *per se*, had no effect, but increased tendency to temper-brittleness of some of the steels was ascribed to small quantities of other elements introduced with the addition agents, and suspicion centred on titanium and zirconium. The work described in this later report was carried out to determine whether these elements were, in fact, responsible for the increased susceptibility to the defect.

The steels previously tested were from a commercial open-hearth heat of the basis composition carbon 0·4, manganese 1·6, per cent. The later investigation was made on two series of low-alloy steels of the S.A.E. 8140 type (carbon 0·43, nickel 0·30, chromium 0·52, molybdenum 0·12, per cent. approx.) melted, respectively, in a basic electric-arc furnace and an induction furnace. Four different types of boron-containing addition agents were used: one contained titanium, one titanium+zirconium, one was a high-silicon material (Borosil), and the fourth was FeB. Two other steels tested were modified, respectively, by additions of titanium or zirconium without boron.

All the steels were given the same hardening treatment (½ hour at 1600°F. (870°C.), followed by oil-quenching), and were tempered for 1 hour at 1200°F. (650°C.). Rate of cooling from the tempering temperature was varied in such a way as to develop temper-brittleness, and isothermal embrittling experiments were also carried out.

The results obtained are shown in summary impact curves, and the transition temperatures of the respective steels were determined on the basis of seven different criteria: minimum temperature corresponding to 0 per cent. brittle fracture, and temperatures corresponding to 50 per cent. brittle fracture, the average energy level, 80 per cent. of the maximum average energy, 40 ft.-lb., 30 ft.-lb. and 20 ft.-lb.

The data indicate that with fully hardened steels tempered at 1200°F. (650°C.) the presence of relatively small amounts of titanium, as introduced into the test steels viâ the boron additions, is sufficient to impair the Charpy V-notch impact properties of the steels, or to cause increased susceptibility to temper brittleness, or to produce both effects. These conclusions were confirmed by the properties found in the steels containing small amounts of titanium without boron. Zirconium additions did not cause deterioration in impact properties. The amounts of that element were very small in the steels tested, but they fell within the residual range usually found in steels treated with addition agents containing zirconium.

Low-Temperature Impact Properties of Cast Nickel-containing Steels

W. J. JACKSON and G. M. MITCHIE: 'The Low-Temperature Properties of Cast Steel.'
Jnl. Iron and Steel Inst., 1957, vol. 187, Oct., pp. 104-20.

The low-temperature applications of steel castings have increased greatly in recent years; castings are employed, for example, in oil-refining plant (where refrigeration equipment frequently operates at temperatures below −100°C.), in ordnance intended for service in arctic conditions, and in high-altitude aircraft. Knowledge of low-temperature properties is therefore of obvious importance, particularly in view of the tendency of some steels to brittle fracture at low temperatures. Data at present available on these properties have been derived mainly from castings of American origin: the work reported in this paper was carried out to secure information on carbon-steel and low- and medium-alloy-steel castings as produced commercially in the U.K.

The steels investigated (supplied by seven different foundries) were in the form of either keel-block or clover-leaf test castings, six from each of three separate heats of steel, of the following types:

0·15–0·20% carbon
0·30–0·35% carbon
1½% manganese
1½% manganese–molybdenum
1¼% chromium–molybdenum
1½% nickel–chromium–molybdenum
2½% nickel–chromium–molybdenum
4% nickel
3% chromium–molybdenum

Certain of the test blocks from each heat of steel were subjected to the heat-treatments which would normally have been used commercially for the respective types. For others, alternative treatments were used, planned to permit investigation of the effect of heat-treatment on impact properties. The

properties of the alloy steels were compared after the following heat-treatments:

(1) Normalizing and tempering, and quenching and tempering.

(2) Normalizing and tempering, and double normalizing and tempering.

(3) Air cooling from the tempering temperature, and water quenching from the tempering temperature.

(4) Quenching and tempering to different hardness levels.

The Charpy V notch was used as the main test and a limited number of tests were also carried out with Charpy keyhole-notch specimens. Vickers hardness tests were made at $+20°$, $-60°$ and $-120°$C., on the materials in each condition of heat-treatment. Data from the individual impact-test curves are given in histogram form, the histograms being derived from the V-notch impact-transition and fracture-appearance-transition curves originally drawn. 'Transition temperatures' were determined from the curves by four arbitrary criteria:—

(1) the 10 ft.-lb. impact level,

(2) the 15 ft.-lb. impact level,

(3) 'Mean energy', i.e., the temperature at which the energy absorbed is the mean of the energies corresponding to the toe and the peak of the impact-energy-transition curve, and

(4) the 50 per cent. fibrous (ductile), 50 per cent. brittle (cleavage) fracture level.

Although the authors emphasize that a steel should not necessarily be regarded as serviceable down to the temperatures associated with these arbitrary levels, they point out that useful deductions can be drawn from the data obtained.

The results for the carbon-steel castings demonstrate the superior impact properties of normalized material, as compared with fully annealed steel, and the advantage of maintaining a low carbon and a relatively high manganese content.

With the 1½ per cent. manganese and manganese-molybdenum steels, quenching-and-tempering gave low-temperature impact properties superior to those produced by normalizing-and-tempering, but, in the case of the latter steel, double normalizing and tempering had no advantage over single normalizing and tempering. For the 1½ per cent. manganese steel, which was subject to temper-brittleness, quenching, *vis-à-vis* normalizing, resulted in significant improvement only if the steel was quenched also from the tempering temperature. Only a slight improvement was achieved by quenching the low-carbon 4 per cent. nickel steel from the tempering temperature. The general effect of lowering the tempering temperature of quenched steels was to reduce the maximum impact value and to raise the transition temperature.

Although the test results do not permit comparison of the low-temperature impact properties on the basis of chemical composition *per se*, it is indicated that optimum results can be secured in such alloy-steel castings only if the alloy content is sufficient to ensure that full hardening is obtained.

Corrosion Fatigue

See abstract on p. 233.

Scale Formation on Nickel Steels

See abstract on p. 231.

Nitriding of Steels

R. W. ALLOTT: 'Nitriding Process.'
Metal Treatment and Drop Forging, 1957, vol. 24, Aug., pp. 335-8.

The author introduces this review by reference to the classic work of Fry, who laid the foundation of the nitriding method of case-hardening. The basic procedure which he developed has remained substantially unchanged: modifications introduced later have been in the direction of minor improvements in technique, closer control of treatment conditions, and adaptation of conditions to widen the range of materials for which nitriding can be used. Such developments have included the use of higher gas pressures and of dual nitriding cycles, also the introduction of new grades of nitriding steel, e.g., chromium-molybdenum and nickel-containing types.

Particular attention has been given to the nitriding of stainless steels. The high chromium content of these steels necessitates special techniques to overcome the influence of the passive film, but by suitable modification of procedure, combined in some cases with treatment of the surface before and/or during nitriding, it is possible to nitride steels of the high-chromium, austenitic chromium-nickel and nickel-manganese-chromium types. In using such steels, the advantages gained and the limitations imposed by the existence of a nitrided surface layer must be duly considered. Combined nitriding-cementation processes have been applied to tool steels.

In the interests of commercial development, much attention has been given to methods by which the period required for nitriding can be shortened: the basic features of the modified processes proposed are reported in this article, and attention is directed to a number of outstanding problems which call for investigation.

Filler Rods and Wires for Gas Welding of Nickel-containing Steels

See abstract on p. 238.

HEAT- AND CORROSION-RESISTING MATERIALS

Sigma Formation in Nickel-Chromium-Iron Alloys

F. B. FOLEY and V. N. KRIVOBOK: 'Sigma Formation in Commercial Ni-Cr-Fe Alloys.'
Reprint from *Metal Progress*, 1957, vol. 71, May, pp. 81-6.
Issued by INTERNATIONAL NICKEL CO., INC., 1957; 6 pp.
See abstract in *Nickel Bulletin*, 1957, vol. 30, No. 9, pp. 169-70.

Production of Nickel Alloys at Wiggin Zenith Works, Glasgow

See abstract on p. 219.

Static and Fatigue Properties of N-155 Alloy

N.A.C.A. SUB-COMMITTEE ON POWER-PLANT MATERIALS: 'Co-operative Investigation of Relationship between Static and Fatigue Properties of Wrought N-155 Alloy at Elevated Temperatures.'
Nat. Advisory Committee for Aeronautics, Report 1288, 1956; 35 pp.

The work described in this report originated in the appointment, by the N.A.C.A. Sub-Committee on Power Plant Materials, of a Special Panel to clarify the principles governing the load-carrying ability of heat-resistant alloys at elevated temperatures, in conditions where creep and fatigue can occur simultaneously.

In view of the sparsity of the data available on fatigue at high temperatures, this Panel arranged co-operative tests designed to obtain comprehensive information on the load-carrying ability of one representative alloy (wrought N-155), as a function of mean and alternating stresses, from static rupture tests to completely reversed fatigue tests.

The ten organisations which co-operated in the investigation were representative of aero-engine makers, aircraft and other research organisations, and Service, university and industrial interests.

Low-carbon N-155 alloy bar stock was selected because (*a*) in the condition in which it was investigated (solution-treated for one hour at 2200°F. (1200°C.), water-quenched, and aged for 16 hours at 1400°F. (760°C.)), it possessed the most uniform properties at high temperatures of any representative 'superalloy' known to the Panel; (*b*) it was metallurgically similar to several forged alloys of the type suitable for application to the gas turbines of jet engines; and (*c*) more experimental metallurgical data were available for this alloy than for any other suitable material. Percentage composition is given as: carbon 0·13, manganese 1·64, silicon 0·42, chromium 21·22, nickel 19·00, cobalt 19·70, molybdenum 2·9, tungsten 2·61, niobium 0·84, nitrogen 0·13. The tests were carried out at 1000°, 1200°, 1350° and 1500°F. (540°, 650°, 730° and 815°C.) and, for comparative purposes, some room-temperature data were also obtained. Conditions were selected to give times-to-fracture varying from 50 to 500 hours. Efforts were made to obtain results from as many types of test machine as possible, and, in particular, to have data duplicated by two types of machine. Full details are given of test procedure used, the preparation of test specimens and the precautions taken to minimize variations in the structure of the test material and its surface finish.

The tests used are listed below:

(1) Sonntag SF-4 axial fatigue tests.
(2) Rupture tests with superimposed alternating bending stress.
(3) Krouse axial-fatigue tests.
(4) Westinghouse reversed-bending-fatigue tests, on specimens having various types of surface finish.
(5) Short-time tensile and rupture tests
(6) Rotating-cantilever-beam tests.
(7) Completely reversed rotating-cantilever-beam fatigue tests.
(8) Completely reversed bending-fatigue tests.
(9) Dynamic creep tests.
(10) Rotating cantilever-beam tests on notched and un-notched specimens, to obtain fatigue, damping and dynamic modulus data.

The conclusions drawn are summarized as follows:

'(1) As the temperature increased, increasingly higher percentages of dynamic stress, superimposed on the steady loads for rupture in 50, 150 and 500 hours, were required to change rupture strength appreciably. At 1500°F. (815°C.) the dynamic stresses approached the completely reversed fatigue strength before a substantial reduction in fracture time occurred.

'(2) As the steady stress was reduced, to increase rupture time, a given amount of superimposed dynamic stress had decreasingly less effect on the time-to-rupture.

'(3) In completely reversed stress tests fatigue strengths were obtained which were of the order of 40 to 60 per cent. of the static tensile strength. As the temperature and time periods considered were increased, fatigue strengths increased relative to static rupture strengths, rising to values of twice the rupture strength for 500 hours at 1500°F. (815°C.).

'(4) Limited data indicated that, under combined stresses up to 67 per cent. of the steady load, the fatigue stress did not appreciably alter the creep characteristics through the second stage of creep. Superimposed fatigue stresses apparently exerted their main influence during the third stage of creep, at least for the material examined and in the test conditions used.

'(5) Properties evaluated on the basis of number of cycles to failure differed from those evaluated on a time basis only when the properties were time-dependent.

'(6) In completely reversed tests, increasing amounts of fatigue loading progressively lowered elongation in the rupture test.

'(7) Bending tests gave slightly higher fatigue strengths than completely reversed axial stress tests. The difference decreased with rising temperature of test, and at 1500°F. (815°C.) the results of the two types of test were comparable. There seemed to be little definite effect from variation in cyclic speed. Axial tests did not show the 'knee' typical of many S-N curves and in all tests the 'knee' tended to disappear with rising temperatures.

'(8) The effect of surface finish became less as the test temperature was raised. Residual stress appeared to be the most significant variable. At low temperatures polished specimens gave higher strengths than ground specimens.'

Complex Hardenable Austenitic Steel: F.V. 520

'High-Tensile Stainless: New Firth-Vickers Steel.' *Iron and Steel*, 1957, vol. 30, Oct., pp. 487-8.

The steel described, which is at present known by its laboratory code designation, F.V. 520, is claimed to combine the high strength and relatively low thermal expansion of a steel of the 2S 80 type (carbon 8·25 max., chromium 15·5-20·0, nickel 1·0-3·0, per cent.) with the corrosion-resisting qualities characteristic of the 18-8 chromium-nickel types. The new steel is of the following composition: carbon 0·07, silicon 1·0 max., manganese 2·0 max., chromium 14-18, nickel 4-7, copper 1-3, molybdenum 1-3, titanium 0·5 max., per cent. It is available in the form of forgings, sheet or wire, and, in slightly varying composition, in cast form. Particulars are given of properties of the steel in various conditions, of suitable heat-treatments and fabrication procedures, welding characteristics, and effect of cold work on response to heat-treatment.

Alumina/Nickel-Alloy Cermets

C. A. HAUCK, E. W. DEADWYLER and T. S. SHEVLIN: 'Alumina-base Cermets.'
Wright Air Development Center Tech. Report 54-173, Pt. II, Mar., 1956; 37 pp.

The aim of the investigation described in this series of reports is the development of alumina-base cermets in which the Al_2O_3 comprises 50 per cent. or less of the total volume of the cermet, and the specification laid down is that the composite materials shall possess a high level of resistance to impact, combined with adequate high-temperature strength and resistance to oxidation. The alloys selected for the metallic constituent were types already developed for high-temperature use, *viz.*, 80-20 nickel-chromium, 65-30-5 cobalt-chromium-molybdenum, 66-18-16 nickel-chromium-iron, 76-24 chromium-titanium and an 18-8 chromium-nickel steel. These alloys were mixed with Al_2O_3 in amounts of 5, 15, 25 and 50, per cent. of the total volume of the cermet.

Much difficulty was experienced, especially in compositions containing relatively high amounts of Al_2O_3, in producing dense cermets suitable for test, and much of the work covered by this report was concerned with methods of producing non-porous specimens, by modifications of both the ceramic and the metal phases, and by changes in sintering conditions, and batch preparation. The fundamental problem was that of the 'wettability' of the Al_2O_3 by the metal phases and some attempt was made to secure better results with the nickel-chromium/alumina cermets by adding small amounts of various agents designed to improve wetting. Although some bonding can be secured between chromium and alumina by slight oxidation of the chromium and subsequent solid solution of the Cr_2O_3 in the Al_2O_3, the problem is complicated in the case of the alloys by the widely differing oxidation potentials of the other constituent metals, and by the limitations on sintering temperature imposed by the relatively low melting temperatures of the alloys. The unsolved problem of devising a means of promoting wetting between Al_2O_3 and the metals iron, nickel and cobalt remains a major obstacle in the development of such cermets.

It was found that a dense body could be sintered, without modification of composition, if the cermets contained less than 15 per cent. by volume of Al_2O_3. Some information is given on the properties of materials of that composition.

Part III of the same series (by C. A. HAUCK, J. C. DONLEY and T. S. SHEVLIN, Mar. 1956; 39 pp.) covers later experiments. The report falls into two sections:

(1) data on production and properties (impact strength and modulus of elasticity) derived from tests on three groups of alumina-containing cermets, and (2) fundamental studies on the wettability of alumina by metals and alloys.

The metallic materials used in the first tests were 80-20 nickel-chromium alloy, Haynes Stellite No. 31 (cobalt-base alloy), chromium-titanium alloy, and silicon. To some of the alloy-base mixtures additions of small amounts of silicon, titanium or silicon carbide were added, to promote wetting.

The results of the firing experiments and of the mechanical tests confirmed the difficulty of bonding experienced in the earlier investigation, and demonstrated the need of a more basic approach to the problem of wettability of Al_2O_3 by metals.

The work relating to that aspect is reported in three sections:—

(1) Literature survey on wettability and the wetting mechanism in metal-ceramic systems, and a report of modifications made in a tungsten-resistor furnace to provide for heating in an inert atmosphere.

(2) Study of the effect of titanium, carbon, and titanium carbide, on the wettability of Al_2O_3 by iron, 18-8 stainless steel, nickel, 80-20 nickel-chromium alloy, cobalt, and Stellite 31.

(3) Examination of polished specimens of cermets containing metallic materials of the above types together with small additions of titanium or titanium carbide, to determine whether the molten metal had flowed into the interstices between the alumina grains, an indication of possible wetting.

It was found that titanium carbide was the best overall agent for promoting wettability. It was effective to the greatest extent, in the following descending order, on stainless steel, nickel, 80-20 nickel-chromium alloy: for iron and Stellite 31 the additional wettability conferred by the carbide was of about a similar degree, and in a cobalt specimen no benefit was derived. Titanium appeared greatly to enhance wetting by stainless steel and Stellite 31, but appeared to have no effect in the case of nickel, cobalt and the 80-20 nickel-chromium alloy. No conclusions could be reached with regard to iron, which did not melt in the specimen. Carbon had no effect on wettability.

None of the specimens showed the amount of wetting that was anticipated, but it is suggested that the relative success of titanium carbide might warrant

consideration of carbides in general as wetting agents, and that borides, nitrides and silicides might also merit study.

Chromium-Nickel-Molybdenum Steel for Use at Moderately Elevated Temperatures

Five specifications issued on Sept. 15, 1957, by the SOCIETY OF AUTOMOTIVE ENGINEERS, relate to steels of the following nominal basis composition: chromium 15·5, nickel 4·5, molybdenum 2·9, nitrogen 0·1, per cent. They cover requirements for the steels in various forms, and applications for which such materials may be used. The series is intended primarily for parts and assemblies requiring high strength and oxidation-resistance up to 800°F. (425°C.).

(1). *A.M.S. Specification* 5743 covers bars, forgings, forging stock and mechanical tubing. Heat-treatment is stipulated, also tensile and hardness requirements for the material in various conditions.

(2). *A.M.S. Specification* 5547 relates to sheet, strip and plate meeting the requirements for strength and oxidation-resistance noted above, and suitable for applications in which welding during fabrication is required. Tensile properties and hardness are specified as in A.M.S. 5743 and a bend test is required.

(3). *A.M.S. Specification* 5781 covers electrodes intended for metallic-arc welding of parts fabricated from material of similar composition. Requirements are laid down with respect to composition of the weld metal to be deposited, quality of the electrodes, coatings, and tolerances.

(4). *A.M.S. Specification* 5780 relates to wire in the cold-drawn, annealed and de-scaled condition, intended primarily for use as bare filler metal in inert-gas arc welding of parts fabricated from material of similar composition.

(5). *A.M.S. Specification* 5554 is concerned with seamless tubing for parts and assemblies such as fluid lines. Specification requirements include heat-treatment, a flarability test for tubing in the annealed condition, and tensile properties after re-annealing precipitation hardening and tempering.

The composition limits laid down in the first four schedules are as follows: carbon 0·10-0·15, silicon 0·50 max., manganese 0·50-1·25, sulphur 0·030 max., phosphorus 0·040 max., chromium 15·00-16·00, nickel 4·00-5·00, molybdenum 2·50-3·25, nitrogen 0·07-0·13, per cent. In the specification for tubing (*A.M.S.* 5554) the composition varies only in the limits specified for the carbon and chromium contents, which are 0·08-0·12 and 16·00-17·00, respectively.

Nickel-containing Materials in Avon Aircraft Gas Turbines

'A Second Century of Avons.'
Aeroplane, 1957, vol. 93, Oct. 11, pp. 552-7.
See also *Flight*, 1957, vol. 72, Oct. 11, pp. 569-74.

One of the most important 'straight' turbojet aero engines yet developed is the Rolls-Royce Avon, of which some thousands have been built and used in a variety of aircraft operated in several countries. The name 'Avon' is used as a generic term to cover two basic series of engines, and is the introductory designation for a range of turbojets of differing powers and design detail. The 100 series of Avons, fully described in *Aeroplane* of Dec. 16, 1955, was basically an engine having a 12-stage axial compressor, eight flame-tube combustion chambers, and a two-stage turbine. Some of the main uses of the 100 series Avons have been in the Hawker Hunter, Supermarine Swift, English Electric Canberra and D.H. Comet aircraft.

In the light of experience gained with the 100 series, some basic and significant changes have been made in design of the 200 series, which are the subject of the present article. Run in November 1951, and flown in February 1953, the first representative of the 200 series went into production in July 1953, and the engines have been developed along two lines, designed, respectively, to meet the needs of civil and military aircraft. The particular features of the compressor, combustion system and turbines, accessories, etc., are described in this article, which is illustrated by a two-page cut-away drawing giving much detail on design.

A further feature of interest is a list of the materials which are used in the major components of a typical Avon R.A. 28. These include:

Variable inlet guide vanes	Weldable austenitic chromium–nickel steel to D.T.D. 171 specification (nickel 6–20, chromium $\leq$12, per cent.).
Guidevane actuating ring	R.R. 58 aluminium alloy.
Compressor shaft, front and rear	Chromium–molybdenum steel to B.S. specification S 106.
Discs	R. ex 448 or Jessop H. 46 ferritic creep–resisting stainless steel.
Blades	
Stages 1–8	Aluminium alloy.
„ 9–11	Stainless steel.
„ 12–15	Titanium alloy.
Front casing	Magnesium-zirconium alloy.
Rear casing	R.R. aluminium alloy.
Flame Tubes	Nimonic 75.
Combustion–system casing	Fortiweld low–molybdenum–boron steel.
Turbine	
Shaft	Chromium–molybdenum steel to B.S. specification S. 106.
H.P. blades	Nimonic 95.
L.P. „	Nimonic 80A.
Discs	R. ex 448 or Jessop H. 46 ferritic creep–resisting steel.
Nozzle box	Centricast 12 per cent. chromium steel.
Nozzle guide–vanes	R.R. nickel–base casting alloy.
Exhaust unit	Nimonic 75.
Hot-air manifold	Fortiweld low – molybdenum – boron steel.
Front and rear wheel–case.	R.R. experimental No. 99 alloy.

Front bearing housing — Magnesium-zirconium alloy.
Rear bearing housing — Fortiweld low-molybdenum-boron steel.

The article closes with some notes on the directions in which further modifications are being introduced into the Avon series, with a view to still greater speed versatility, improvement of thrust-reversal, reduction of exhaust noise, and other details. In addition to such refinements in the Avon series itself, the experience gained with this family of engines is being applied in development of the Conway type, with which Rolls-Royce designers are now actively engaged.

Nickel Alloys in the Ruston Gas Turbine

'The Second Ruston Gas Turbine.'
Oil Engine and Gas Turbine, 1957, vol. 25, Sept., pp. 194–8.

The article gives a detailed description, with cut-away diagram, of the single-shaft 430 b.h.p. Mark TE gas turbine developed by Ruston and Hornsby, Limited. For several years the Company has concentrated on development of one type of gas turbine, the 1300-b.h.p. Mark TA. With that model firmly established, work has been extended to engines of different design and power range, of which the Mark TE 430 b.h.p. is the first to reach the production stage.

Since the turbine is of the non-recuperative simple-cycle type, thermal efficiency is low (12 per cent.) and the unit is intended for operation in conjunction with a waste-heat boiler, or for applications, such as marine auxiliary electricity generation, where the rate of fuel consumption is not of primary importance.

Particulars of the materials used for the major parts of the engine include reference to nickel-containing alloys which, originally developed for use in aircraft gas turbines, are now being increasingly adopted in stationary types. Thus, all three stages of the moving blades of the Mark TE engine are machined from Nimonic 90 bar material; Nimonic 75 is used for the stator blades, the flame tube and the turbine inlet volute; high-alloy nickel-chromium steel foil protects the heat-insulating blanket of the inlet volute, and austenitic steels are used also for some other components, e.g., the stator segments.

As with the earlier Ruston engine, design has been for long life: with the TE Model about 25,000 hours of full-load operation are expected before complete overhaul, and possible replacement of high-temperature components, are necessary.

Bearing Characteristics of Nickel-base Alloys

See abstract on p. 219.

Electrical Characteristics of Evanohm Resistance Alloy

C. D. STARR and T. P. WANG: 'The Electrical Characteristics of a Nickel–Chromium–Aluminium–Copper Resistance Wire.'
Proc. Instn. Electrical Engineers, Pt. B, 1957, vol. 104, Sept., pp. 515–18.

A report of the electrical characteristics of the resistance alloy known commercially as Evanohm was published in 1956 (*ibid.*, vol. 103, pp. 439–47; *Nickel Bulletin*, 1956, vol. 29, Nos. 10–11, p. 193). It was pointed out that this alloy (nickel 75, chromium 20, aluminium 2·75, copper 2·0, per cent.) has many of the properties desirable in a precision resistance alloy, e.g., stability of resistance over a considerable temperature range, high resistivity, good yield and tensile strengths, and a degree of ductility rendering it suitable for drawing to fine wire which will give high resistance per unit length. In the course of the earlier work certain observations were made with regard to the influence of heat-treatment on the resistance of Evanohm, and the authors now report further studies of this aspect. The paper is concerned with the nature of the resistance change occurring during heat-treatment, the effect of heat-treatment on Evanohm wire, the relation between resistivity and temperature coefficient of resistance at various temperatures, and the variables affecting the resistance of the heat-treated alloy wire.

In view of the nature of the resistance-temperature curve and from a consideration of X-ray data, it is proposed that the electrical changes observed be attributed to short-range order. It is shown that both the mean temperature coefficient of resistance and the minor deviations in linearity found on the resistance/temperature curve vary in a systematic manner during heat-treatment and that these changes are independent of the prior thermal history of the material.

In connexion with variables influencing stability of resistance at elevated temperatures, it is shown that surface tarnishing may cause appreciable drift in resistance and that mechanical strain may result in decrease in resistivity, accompanied by increase in temperature coefficient. In production of ultra-precision resistances it is therefore essential to minimize strains.

Intergranular Oxidation in Stainless Steels and Nickel-base Alloys

C. A. SIEBERT, M. J. SINNOTT, L. H. DESMYTER and H. M. FERRARI: 'An Investigation of Intergranular Oxidation in Stainless Steels and High-Nickel Alloys.'
Wright Air Development Center Tech. Report 55-470, Pt. II, Oct., 1956; 42 pp.

Intergranular oxidation is a factor of considerable importance in applications in which thin metal sections are exposed to air at high temperatures. In such conditions the proportion of the metal affected by the oxide fissures is a significant percentage of the whole section and oxidation may result in premature failure.

The experiments described in this report were planned to obtain, for the use of the U.S. Air Force, information on intergranular oxidation liable to occur in a typical heat-resisting chromium-nickel steel and two representative nickel-base alloys. The test variables were arranged to permit assessment of the effect of temperature and stress on progressive internal oxidation, and the minimum stress level at which

intergranular penetration increases rapidly at temperatures of 1200°F. (650C.) and above. The point at which this change occurs is designated 'the threshold stress'. The test programme also provided for measurement of the oxidation rates on the basis of gain in weight at various stages of exposure and for the study of sub-surface oxides.

The materials tested were Chromel ASM (nickel 77·65, chromium 19·81, silicon 1·43, per cent.), two Type 310 steels (chromium 25, nickel 20, per cent., one commercially produced and one vacuum-melted), and Hastelloy B (molybdenum 28·01, iron 5·19, per cent., balance nickel with minor amounts of other constituents). The test samples were in the form of standard strip specimens $\frac{1}{2} \times 2$ in. gauge portion.

Measurement of weight gain at various intervals during oxidation, over the temperature range 1200°–2000°F. (650°–1095°C.), showed that most of the materials followed the parabolic oxidation law. The Chromel ASM alloy had the lowest parabolic rate constant and the Hastelloy B the highest one. The constants of the two heat-resisting steels were approximately the same.

At temperatures of 1900° and 2000°F. (1035° and 1095°C.) the threshold stress occurred at approximately the same value for the Chromel ASM alloy and the two austenitic steels.

Formation of Oxide Films on Stainless Steels

H. J. YEARIAN, W. D. DERBYSHIRE and J. F. RADAVICH: 'The Formation of Oxide Films on Chromium and 18Cr–8Ni Steels.'
Corrosion, 1957, vol. 13, Sept., pp. 597t–607t.

Detailed X-ray diffraction investigations of the oxide scales formed on chromium and nickel-chromium steels oxidized in air and oxygen for 100 hours, at temperatures within the range 1600°–2200°F. (870°–1205°C.), have already been reported by YEARIAN, BOREN and WARR (*ibid.*, 1956, vol. 12, Nov., p. 561t; see abstract in *Nickel Bulletin*, 1957, vol. 30, No. 1, p. 17). The present paper details the results of a complementary study, by various methods, of thin oxide films formed on chromium and nickel-chromium steels at lower temperatures and after shorter times than are necessary for the formation of true oxide scales. The steels, exposed in the form of sheet, included conventional low-carbon straight-chromium types containing 6–19 per cent. chromium, a group representative of low-carbon 26 per cent. chromium steels (with varying minor amounts of other elements), and three 18–8 chromium-nickel steels of the S.A.E. 303 and 302 types. Four other materials were included in the tests, to give an additional check on the general validity of the conclusions drawn with regard to the stainless steels. These four were of the following types: 80–20 nickel-chromium alloy, high-chromium steel containing 0·35 per cent. carbon, a high-carbon die steel and a steel typical of the S.A.E. 1020 grade 0·18–0·23 per cent. carbon).

The study was confined to oxide films formed during exposure for various periods to oxidation in air at temperatures in the range 300°–700°C. (Less extensive investigations have shown that oxidation in pure oxygen gives similar results.)

To obviate disturbance of the surfaces resulting from mechanical polishing, which could have had a significant effect on oxidation, most of the specimens were electrolytically polished. The same electrolyte was used to loosen the oxide film prior to stripping for examination.

The physical conformation of the outer surface of the oxide was examined by electron microscopy, using the chromium showcast Formvar replica technique; reflection and transmission electron diffraction methods were used to identify the oxides present and to determine lattice parameters, composition of solid solutions, etc., and the relative intensities of the various phase patterns obtained by X-ray diffraction were utilized as a measure of the relative amounts of the respective phases present in the whole sample.

The results are reported in three main sections: (1) physical structure and growth of the oxide films (illustrated by photomicrographs); (2) micrographic observations with regard to the rôle played by recrystallization, surface preparation, minor constituents present in the 26 per cent. chromium steels, and film thickness; (3) composition and structure of the oxide films.

The authors summarize their findings as follows:

'The formation of oxide films on chromium and nickel-chromium steels in air in the range studied may be described as follows:

'A thin uniform film, composed of small crystals of a ferric-chromic oxide solid solution, forms very quickly with a [111] fibre axis normal to the surface. Under this film there may be a very thin layer of an Fe–Cr or Fe–Cr–Ni spinel-type oxide. As time goes on the film increases in thickness at a decreasing rate and its chromium content increases. The crystal size increases and the preferred orientation becomes more nearly complete. During this growth of the base film its protective power fails at essentially randomly distributed points, whereupon a rapid local growth occurs in the form of polycrystalline nodules of αFe_2O_3, or of a low-chrome Fe_2O_3–Cr_2O_3 solid solution, overlying a small amount of Fe–Cr spinel. A high-chromium rhombohedral solution may also occur in the nodules. This phase is favoured by the presence of silicon, but it is suppressed by 9 per cent. of nickel in the alloy. These components are oriented, but to a decreasing degree as growth continues.

'Eventually the whole surface becomes covered with nodules. The frequency with which local failure occurs and the rate of growth after breakdown are decreased by a decrease in temperature and by an increase in the chromium content of the alloy. Small amounts of silicon and manganese also tend to reduce the rate of attack.'

Scale Formation on Nickel Steels

K. SACHS: 'Mechanism of Formation of Metal Particles in Scale on Nickel Steels.'
Jnl. Iron and Steel Inst., 1957, vol. 187, Oct., pp. 93–104.

This paper continues a series describing the nature of the scale formed on nickel-containing steels under oxidizing conditions. References to earlier publications are given in the *bibliography*.

From a survey of the observations made throughout the experimental work it is concluded that the metal particles entangled with the oxide in the inner layer of the scale on nickel steels form by the competitive operation of two mechanisms: the preferential oxidation of iron, leading to the enrichment in nickel of metal entrapped in the advancing scale, and the transient solution of nickel in the Wüstite, followed by its precipitation on suitable nuclei. Metal particles interrupt the counter-current diffusion of metal and oxygen ions through the oxide lattice, performing a function similar in principle to porosity. By the aid of these concepts it is possible to account for the effect of furnace atmosphere and nickel content on the structure of the inner scale layer and for the distribution of metal particles and of nickel through the thickness of the scale.

Techniques for Studying Corrosion and Metal Transport in Fused Sodium Hydroxide

G. P. SMITH, M. E. STEIDLITZ and E. E. HOFFMAN: 'Corrosion and Metal Transport in Fused Sodium Hydroxide. Part I—Experimental Procedures.'
Corrosion, 1957, vol. 13, Sept., pp. 561t–4t.

This paper describes techniques used to study corrosion and mass transfer of metals in fused sodium hydroxide, at temperatures up to 815°C. It serves as an introduction to subsequent papers which will give details of the investigation and report the data obtained.

The tests were planned so as to conform with the following conditions which previous research had shown to be essential: only one metal or alloy should be exposed to the hydroxide melt; the hydroxide melt should be kept as isothermal as possible; the blanketing atmosphere should be rigidly controlled; exposure of sodium hydroxide to air, prior to use in corrosion tests, should be minimized.

The test techniques discussed and the variables they were designed to evaluate are (1) *the capsule test*, used to obtain an initial evaluation of corrosion-resistance; (2) *the cold-finger test*, used to study mass transfer under the influence of a thermal gradient; (3) *the controlled-atmosphere test*, planned to determine the effect of atmosphere on corrosion in the absence of mass transfer.

Nickel-containing Materials in Uranium-Recovery Plant

G. I. CATHERS: 'Uranium Recovery for Spent Fuel by Dissolution in Fused Salt and Fluorination.'
U.S. Atomic Energy Commission Report O.R.N.L.—CF-57-1-18, Jan. 29, 1957; 19 pp.

The report describes a non-aqueous process for recovery of uranium from spent fuel elements. Results at the pilot-plant stage indicate that the procedure holds considerable promise. In the installation used in these tests all the salt-process vessels are constructed from nickel or high-nickel alloys: specific reference is made to use of Monel and Inconel.

Corrosion of Nickel-containing Aluminium Alloys in High-Temperature Water

F. H. KRENZ: 'Corrosion of the Aluminum-Nickel Type Alloys in High-Temperature Aqueous Service.'
Corrosion, 1957, vol. 13, Sept., pp. 575t–81t.

The author introduces his paper by reference to the investigations by Draley and Ruther which led to the development of an aluminium alloy containing 1 per cent. of nickel, found to be resistant, at temperatures of the order of 250°–350°C., to the localized blister corrosion to which pure aluminium and some of its alloys are subject in high-purity water above 200°C. (See *U.S. Atomic Energy Commission Report ANL*-5430, July 1955; abstract in *Nickel Bulletin*, 1956, vol. 29, No. 7, pp. 145 and 142.)

In alloys susceptible to the localized attack, blisters formed in the metal adjacent to the surface disrupt the surface layers and break the protective film, thus greatly accelerating attack. Additions of nickel and iron to aluminium result in formation of a nickel-iron-rich second phase which is cathodic to the aluminium matrix, and the particles of the second phase, if suitably distributed (at the grain boundaries) in the alloy, have the property of changing the localized attack to a uniform penetration of the surface, producing an unbroken surface film.

Since the corrosion rates of the modified alloys in static water at temperatures as high as 350°C. are in the region of only 10^{-3} in./year they hold promise for use in nuclear-power reactors, and this paper reports an investigation, carried out at Atomic Energy of Canada, Ltd., to determine the suitability of the alloys for such applications, in particular as materials of construction for sheathing fuel elements in water-cooled reactors.

The investigation fell into three parts: (1) Short-term tests to determine the effect, on corrosion-resistance, of the composition of relatively complex ternary and quaternary aluminium alloys containing Ni, Cu, Fe and Si; (2) measurements of long-term corrosion rates of the more promising alloys, in static water at 250°–300°C. ; (3) tests, in flowing water, on solid cylinders or tubes with welded end-caps fabricated from selected alloys.

Static corrosion tests were carried out at 300°C. in standard autoclaves and the specimens were removed for examination at intervals of one week. Dynamic-loop tests were performed at 260°C. and at flow velocities of 18–20 ft./sec., for periods varying from two to six weeks. Corrosion-resistance was assessed by the following criteria: visual examination, weight gain, weight loss after removal of the corrosion film, and dimensional changes. The specimens were also subjected to microscopic examination.

The short-time 'seeding' corrosion tests led to

selection of three compositions as meriting more detailed study: see table below.

Alloy	Ni %	Cu %	Fe %	Si %
151	2·05	2·13	0·25	0·09
155	0·53	0·002	0·49	0·21
157	2·00	0·002	0·48	0·21

It is noted that the silicon content is optimum in the region of 0·2 wt. per cent. The author can give no explanation for this effect, but suggests a relationship between silicon content and the size and distribution of the Al-Fe-Ni intermetallic particles. With a silicon content of 0·2 per cent. the second-phase particles were relatively small and finely divided, whereas at 0·5 per cent. silicon they were coarse and widely separated. Examination of the structure of these alloys confirmed the observations made by Draley and others.

In the second stage of the investigation corrosion rates of the three selected alloys were determined by long-term static corrosion tests at 300°C. and evaluated by the criteria used in the earlier experiments. It was observed that the corrosion films had a characteristic double-layered structure: one film, designated type A, was porous and grew outward from the metal; the other, B, grew into the metal, was denser, and, in contrast to the outer layer, contained particles of the second phase. Film A reached a limiting thickness after two to three weeks, but film B continued to grow linearly with time. At the 2-3 weeks' stage the corrosion rate was acceptably low (app. 1×10^{-3} i.p.y.), but the corrosion film was 10-20 μ thick and relatively brittle. Gain in weight was found to be a reliable measurement of static-corrosion rates and, since an increase in the thickness of any protective film would cause a corresponding diminution of the corrosion rate, it is thought that film B cannot be of a protective nature.

The results show that the alloys are satisfactorily resistant under the test conditions, but that the low corrosion rates are reached only after the formation of corrosion films of 10-20 μ thickness.

Dynamic corrosion tests previously made on nickel-containing aluminium alloys had indicated that attack takes place by an erosion-corrosion mechanism, but this explanation is not yet universally accepted. Data presented in this report, on long-term loop-test results, appear, however, to support that view. Some tentative suggestions are made in explanation of the effects observed at various stages of these tests.

Summarizing the practical implications of the tests, it is concluded that the friability of the corrosion film and the relatively poor mechanical properties of the aluminium-base alloys at high temperatures are the main obstacles to the use of these materials at their present stage of development. Efforts must therefore be directed towards effecting improvement by (*a*) modifications in the alloys or their environment, to ensure that the protective film is thinner and less likely to crack or flake, and (*b*) increasing the strength of the alloys at service temperatures.

Tests in which the selected alloys were evaluated as actual fuel sheaths on specimen fuel elements showed that reactor radiation has only an insignificant influence on corrosion, and it is likely also that heat fluxes of the order of 100 watts/cm² also have little effect on susceptibility to attack.

Stress-Corrosion Cracking of Nickel-Chromium Stainless Steels in the Presence of Chlorides

H. R. COPSON and C. F. CHENG: 'Some Case Histories of Stress-Corrosion Cracking of Austenitic Stainless Steels associated with Chlorides.'

Reprint from *Corrosion*, 1957, vol. 13, June, pp. 397t-404t.

Issued by INTERNATIONAL NICKEL CO., INC., 1957; 8 pp. See abstract in *Nickel Bulletin*, 1957, vol. 30, No. 9, p. 174.

Effect of Pre-Stressing on the Fatigue Life of Stainless-Steel Tubes

C. S. YEN and B. V. WHITESON: 'Improving Fatigue Life of Formed Stainless Steel Hydraulic Tubing by Pre-stressing.'

Wright Air Development Center Tech. Report 56-120, May 1956; 51 pp. *P.B.* 121969.

In previous work on the fatigue strength of hydraulic tubing tested under internal pressure pulsing it was found that formed portions of the lines had a lower fatigue life than straight portions. Three methods of improving the fatigue life of the formed portions were recommended: pre-stressing, minimizing the flattening of the cross-section in the formed portion, and improving the surface roughness. The work now described deals with pre-stressing experiments. The programme provided for determination of:

(1) the effect of pre-stressing, on the fatigue life of formed tubes;

(2) optimum pre-stressing pressure;

(3) tube deformation resulting from pre-stressing;

(4) methods of correcting tube deformation;

(5) effect, on fatigue life, of re-forming after pre-stressing;

(6) factors affecting freezing of end fittings.

The specimens, which were of steel conforming to U.S. specification MIL-T-6845, had the following composition: chromium 20·60, nickel 9·29, manganese 1·38, silicon 0·25, copper 0·09, molybdenum 0·20 max., carbon 0·045, per cent. Wall thickness of the tubes was 0·028 in. and their outer diameters varied from $\frac{3}{16}$ to $\frac{3}{4}$ in., according to the purpose of the test.

In forming the tubes, work was controlled so as to produce either 5 per cent. or 10 per cent. flattening in the formed portion. Pre-stressing consisted in

applying a high hydrostatic pressure to the tubing, after forming and before fatigue testing. Full details of equipment and technique used in all the experiments are given in appendices to the report.

The results indicate that within certain limits pre-stressing improves fatigue life of formed tubing under repeated pressure pulsing. There is, however, the disadvantage that pre-stressing also produces distortion or permanent deformation, which could render unacceptable tubing supplied to close tolerances. Tests on tubes which had been flattened 5 per cent. showed that by the use of rigid restraint, with a heavy clamp in pre-stressing, or by subsequent re-forming, the distortion produced by pre-stressing can be prevented or corrected. Under such conditions, however, the gain in fatigue life obtainable by pre-stressing is lost. As a compromise, it is possible, by using a light clamp in pre-stressing, to restrain deformation to some extent, without appreciably sacrificing the gain in fatigue life.

It is concluded that for formed tubes designed for a given power transmission and required to survive one million cycles of constant-pressure pulsing, a weight saving of 12–35 per cent. can be achieved by pre-stressing, if the treatment is applied without rigid restraint and there is no subsequent re-working, and if the maximum pulsing pressure in service is not more than half the bursting pressure of the tubing.

Corrosion Fatigue

T. D. WEAVER: 'Corrosion Fatigue.'
Chemistry and Industry, 1957, Sept. 7, pp. 1190–4.

This paper is a condensed discussion of the deleterious effect of combined corrosion and cyclic stress, the mechanism of failure under such conditions and the counter-measures which can be taken.

The author defines corrosion-fatigue and the terms used to evaluate it, and discusses the effect of mechanical and chemical notches in the metal, on susceptibility to corrosion-fatigue. Methods of test used to assess susceptibility are also considered, with discussion of the effect of test variables (e.g., rate of cycling, strength of corrodent, etc.). Corrosion-fatigue resistance is considered as affected by the surrounding medium (air, fresh water, salt water): data on typical materials are reviewed. The information given relates to bronzes, aluminium alloys, plain and low-alloy steels and high-chromium and chromium-nickel stainless steels.

A résumé is also made of methods by which a metal may be protected by surface treatment, e.g., by electrodeposition of various metals or by galvanizing, nitriding, shot-peening or appropriate heat-treatment. The influence of such treatments, on resistance to fatigue, is discussed, and attention is drawn to the fact that indiscriminate use of electroplating can lead to accelerated failure. The résumé is supported by data on the effect of protective coatings of nickel, chromium and other materials on the fatigue-resistance, in air, of mild, medium-carbon and alloy steels. Among the basis materials for which values are given are some nickel-chromium steels.

Mention is made of recent developments by which the tensile stress in electrodeposited coatings may be lowered, thus minimizing any deleterious influence of the coating on the fatigue-resistance of the basis metal.

Resistance of Materials to Corrosion by Formaldehyde

E. LINGNAU: 'The Behaviour of Materials in Contact with Formaldehyde.'
Werkstoffe und Korrosion, 1957, vol. 8, Aug.–Sept., pp. 480–7.

This paper is essentially an annotated survey of the literature on the resistance of metallic, organic and inorganic materials to corrosion by formaldehyde and its aqueous solutions. The supporting *bibliography* contains 79 references.

As an introduction, the properties of gaseous and liquid formaldehyde, its aqueous solutions and its polymerisation products are briefly reviewed and an outline is given of the principal method by which formaldehyde is produced (oxidation of methanol). Its main applications are also considered.

The section devoted to the behaviour of metals in the presence of formaldehyde opens with reference to factors which inhibit or promote corrosion. The deleterious effect of formic acid (produced by oxidation of formalin in the presence of metals) is emphasized and various measures which have been found effective in inhibiting such oxidation are reviewed. Pure solutions of formaldehyde have, in general, no corrosive effect, but the presence of impurities may make it corrosive, and addition of formaldehyde to acids such as formic, acetic or propionic can increase the rate of attack of the acids on steel, tin, lead, aluminium and copper. More frequently, however, addition of formaldehyde to other solutions has an inhibiting effect: examples are given of the industrial utilization of this property in the production of non-acidic and acidic substances containing hydrogen sulphide, e.g., natural gas or oil. The discussion is supported by tabular data on the resistance of various metals to corrosion by aqueous solutions of formaldehyde, and the effect of the metals on the stability of such solutions. As a corollary, the suitability of various metallic materials for the construction of plant handling formaldehyde is discussed. These data include information relating to nickel, Monel, 18–8 type chromium-nickel steels, Inconel, Durimet T, Worthite, copper-free Ni-Resist, and a nickel-copper alloy.

Aluminium and its alloys have very high resistance to corrosion by formaldehyde, and are frequently used for equipment handling it. A major part of the section on metallic materials is therefore devoted to aluminium-base alloys.

The stability of nickel-chromium stainless steels in the presence of solutions of formaldehyde is exemplified by reference to specific applications of 18–11 chromium-nickel steel and chromium-nickel-molybdenum types. Copper also gives good resistance, and among the copper alloys considered

suitable for industrial applications mention is made of copper-nickel and copper-nickel-zinc alloys.

The paper ends with a discussion of the resistance of various ceramic, rubber, synthetic and natural materials to attack by formaldehyde.

Galvanic Corrosion in Water Meters Incorporating Nickel Alloys

H. F. BARRETT: 'Galvanic Corrosion in Water Meters.' *Jnl. Amer. Water Works Assocn.*, 1956, vol. 48, Oct., pp. 1274–8.

The author draws attention to the heavy cost resulting from galvanic corrosion of water-meter parts, particularly in large-scale installations in cases where the deterioration causes stoppage of registration. Meter manufacturers have adopted various means for minimizing the risk of such corrosion, and progress has been achieved, but the author considers that there has been insufficient public discussion of the problem, and that there has been inadequate attention to the principles underlying the mechanism of galvanic corrosion as occurring in water meters. This paper is designed to put the matter into perspective by assembling data on the various types of couple which may occur in water-meter service, the nature of the attack, and the means by which it may be avoided. The information on which the paper is based stems from three sources: (1) studies made by the author and others for the Buffalo Meter Company; (2) investigations on corrosion of water meters carried out by the Engineering Institute of the University of Michigan, and (3) observations made by International Nickel Company, in the course of extensive studies of corrosion and by contact with other organizations.

The present review covers eleven types of galvanic corrosion which may occur in meters. *Inter alia*, the following couples involving nickel-containing materials are discussed: nickel-bronze/bronze, bronze/Monel, bronze/chromium - nickel stainless steel. The discussion includes critical commentary on the limitations of laboratory test results in predicting service behaviour.

Slag Treatment of High-Alloy Steels

'Slag Scrubs Stainless.'
Steel, 1957, vol. 141, Sept. 30, p. 86.

The slag-washing technique described in this short article was developed by Eastern Stainless Steel Corporation, Baltimore, in co-operation with the Linde Company, a division of Union Carbide Corporation. The Companies claim that its use prevents formation of deleterious stringer-type inclusions often present in titanium-stabilized stainless steels, and eliminates banding and segregation. Slag-washing was first successfully applied to an 18-8 titanium-stabilized chromium-nickel steel, but has been found suitable also for many special types of austenitic steels used for high-temperature service, e.g., 19-9 DL, A-286 and 19-9 DX, as well as for ordinary commercial grades of stainless steel for polished sheet.

The sequence involved in the process is as follows: The steel is melted in an induction furnace, in which, as a result of the induction current, the metal is in constant motion, thus forcing any contaminants to the surface of the melt, from which they can be removed. Prior to teeming of the steel, a measured amount of a special liquid slag (previously melted in an adjoining arc-furnace and at a temperature of 3000°F. : 1650°C.) is poured into the ingot mould. At the pouring temperature (2600°–2800°F.: 1425°–1540°C.), the molten steel is not transferred to a ladle, where contamination might occur from the refractory, but is cast direct from the furnace into the mould. As the steel flows through the blanket of slag any contaminants present are removed, and, by forming a protective layer on the surface, the slag also prevents oxidation. Since the high temperature of the slag retards the rate of solidification, low-density contaminants are given time to float to the top of the ingot before solidification.

Deformation of Metallic Surfaces by Abrasion and Polishing

See abstract on p. 214.

Selective Etching of Stainless-Steel Plaques

'Etch Stainless Plaques Quickly and Profitably.' *Iron Age*, 1957, vol. 180, Sept. 12, pp. 132–3.

Nickel-chromium stainless steel can be etched quickly, easily and economically, to serve many decorative purposes, e.g., presentation and commemorative plaques. An added advantage is that the material is durable and can be given a surface finish which is aesthetically pleasing and virtually permanent. Compared with more conventional types, stainless-steel plaques cost less in terms of material and labour, and good results can be obtained with relatively little equipment and experience. This article gives details of procedure used by Metal Etching Corporation, Queen's, N.Y.

All the high-alloy stainless-steel series can be used for this purpose, but the nickel-chromium (S.A.E. 300 series) is preferred, on account of its corrosion-resistance and colour stability. Compositions of five etchants used for production of plaques are given below:

	Parts
(1) Nitric acid (60%)	10
Hydrofluoric acid (45%)	4
Water	86
Used at 130°–140°F. (54°–60°C.)	
(2) Nitric acid (60%)	12
Hydrofluoric acid (45%)	5–6
Water	82–83
Used at 130°–140°F. (54°–60°C.)	
	Grams
(3) Ferric-chloride hydrate	625
Ammonium chloride	44
diluted to	1 litre
	Parts
(4) Ferric-chloride solution (20–30%)	4
Commercial hydrochloric acid	1
Commercial nitric acid	1/4

		Parts
(5) Hydrochloric acid	by weight	100
Mercurous nitrate	,, ,,	6·5
Water	,, ,,	100

It is stated that solutions (1) and (2) give a light etch in 15 minutes to one hour. No. (3) produces a relatively deep etch in about one hour, at room temperature, and Nos. (4) and (5) result in deep etches in 20–45 minutes at the same temperature. In cases where nitric acid is used it acts as an inhibitor and the concentration of the solution must be carefully controlled to avoid pitting of the steel surface.

When a number of identical plaques are to be produced, the original image and text are photoengraved on a printing plate and the plate and the blank to be etched are placed together in a printing press. The stainless-steel blank is then offset printed and the surface, with the exception of the areas on which there is to be a design, becomes coated with ink.

While the ink is still wet, the blank is dipped into finely ground asphaltum, which adheres only to the tacky ink and which, after the plate is heated, fuses to form a protective acid-resistant layer, leaving the exposed areas sharply outlined and ready for attack by the etchant. If only one plaque is to be made, the printing-plate stage is omitted, and the whole of the plaque is covered with a 'resist', which is then cut or engraved away from the areas which are to be etched.

In both cases the next stage consists in etching for the required time, and rinsing. Excellent definition is achieved and no further finishing is required.

Finally, the steel surface is buffed, the plate is trimmed and mounting holes are drilled. If the plate is to be coloured, enamel is sprayed into the etched depressions and hardened by heating.

Nitriding of Stainless Steels

See abstract on p. 225.

Inconel in the Paper-Making Industry

J. F. NATION and J. M. TULL: 'How Lining with Inconel Combats Digester Corrosion.'
Paper Industry, 1957, vol. 39, Apr., *Sect. I*, pp. 33, 36.

Corrosion in carbon-steel pulp digesters has, for the past 10–15 years, been a matter of growing concern in the paper-making industry, but a development some five years ago appears likely to solve the problem. Sixteen digesters fabricated from steel clad with Inconel (nickel 77, chromium 15, iron 7, per cent. alloy) were placed in operation five years ago, and, to date, are showing outstanding resistance to corrosion and deterioration.

This development is the outcome of an extensive research carried out by The International Nickel Company, Inc., in collaboration with several paper mills. Laboratory tests, and service trials with spool-test specimens exposed in various critical locations in pulping mills, were made with various materials believed to be promising for this type of work. Another exhaustive series of tests was sponsored by the TAPPI Digester Corrosion Sub-Committee, involving the study of digester corrosion in 97 units, operating in 14 mills. Results in both test series pointed conclusively to the satisfactory corrosion-resistance of Inconel-clad vessels. This superiority is considered to be due to the following properties of the material:

Intrinsic resistance to attack by alkaline cooking liquors.

Freedom from susceptibility to stress-corrosion cracking, even in the presence of concentrated white liquors or mixtures of black and white liquors, at elevated temperatures.

Coefficient of thermal expansion closely similar to that of the carbon steel to which the Inconel cladding is bonded. This similarity in expansion minimizes difficulties which could otherwise result from variations in temperature involved in the heating and cooling cycles of the digester.

The cladding and lining is currently being done by three different processes: the Lukens method, involving hot-rolling of plates of steel and of Inconel; the Hortonclad process, which produces a bimetallic plate by fusing a corrosion-resistant layer onto a heavy steel backing plate, and the Smithlining method, in which resistance spot welding is employed to bond the alloy lining to the steel. All three methods produce a composite having a high degree of strength combined with the requisite corrosion-resistance.

Successful results with Inconel-clad digesters are being reported from a number of mills in the U.S.A.; some typical records are quoted in this article.

Processes and Materials of Construction in the Chemical and Chemical-Engineering Industries

Industrial and Engineering Chemistry of September 1957, volume 49, No. 9, Pt. II, contains The Tenth Annual Unit Processes Review and The Eleventh Annual Materials of Construction Review.

As in earlier reviews, the articles are based on the literature which has appeared since the previous publications, but a welcome innovation is the introduction of each article by a condensed commentary on the highlights of recent developments in the respective fields. The scope of the publication is indicated by the subject titles of the two sections listed below: fuller details are given of reviews which have specific reference to nickel-containing materials.

TENTH ANNUAL UNIT PROCESSES REVIEW

Alkylation; amination by reduction; combustion; decomposition of hydrocarbons; esterification; fermentation; halogenation; hydration and hydrolysis; hydrogenation and hydrogenolysis; isomerization; nitration; polymerization; pyrolysis of coal and shale; sulphonation and sulphation; Friedel-Crafts acylations.

The chapter on *hydrogenation* (pp. 1523–31) refers to many uses of nickel-containing catalysts, emphasizing their particular significance in processes in

which saturation is the object. Most of the commercial processes in this field use nickel precipitated on a carrier or nickel obtained by decomposition of the formate. Frequent reference is made also to the use of Raney catalysts. This review includes a useful reference table showing the nature of the catalysts used in ten main groups of industrial process, and of types which have been employed in fundamental studies of catalytic reactions. The supporting *bibliography* (238 items) is classified in a similar manner, under the headings hydrogenation of carbon oxides; the Oxo process; ammonia synthesis; acetylenes, olefins and aromatics; petroleum, coal and related materials; organic compounds; fundamental studies.

11th ANNUAL MATERIALS OF CONSTRUCTION REVIEW

Aluminium alloys; carbon and graphite; ceramics; elastomers; fibres; hard rubber; lead and its alloys; less common metals (zirconium and hafnium; molybdenum; niobium and tantalum, rhenium; chromium); nickel, including high-nickel alloys; plastics; protective coatings (non-metallic); stainless steels, covering also high-silicon irons, iron-nickel alloys, and austenitic manganese steel); tin and its alloys; titanium.

Nickel and High-Nickel Alloys (pp. 1618–28)

This review is divided into five main sections, covering, respectively, mining, production and availability of nickel; physical metallurgy research and development; welding and fabrication; materials for high-temperature applications, and other applications of nickel and nickel-base alloys. Among the aspects of the literature to which particular attention is directed are the following:

(1) Increase in production of nickel from Canadian and Cuban mines, and prospects of ampler supplies of the metal from 1960 onwards.

(2) Development of improved high-temperature alloys, and further research aimed at producing materials which will withstand the extremely high temperatures involved in rocket and guided-missile operation. Methods being studied in this connexion include vacuum melting and the use of inert hard particles for stiffening the matrix of alloys.

(3) Advances recently made in welding techniques suitable for nickel alloys and clad materials, and the development of more discriminating tests of welds.

(4) Progress in understanding of the effects involved in machining of high-alloy and other materials, and of the fundamental influence of other forming operations.

(5) Literature on the resistance of Monel and other nickel alloys to specific corrodents, e.g., bromine, caustic, fluorine, sulphuric acid, sea and salt water.

(6) Applications of high-nickel alloys in the pulp and paper industry, in electronic equipment, in the petroleum industry, and in the field of nuclear energy.

Stainless Steels, including Other Ferrous Alloys (pp. 1643–52)

Features of recent development have included modified compositions, to effect economy and to enhance properties required in specific applications, and improved welding and fabrication techniques, which have made possible successful utilization of stainless steels of many types. Further work has been done on methods for determination of susceptibility to intergranular corrosion, and research on stress-corrosion cracking is being intensified. Recent literature has contained also useful data on resistance of stainless steels to individual corrodents encountered in some specialized applications. From the metallurgical aspect, reports have been published on the effect of cold work on mechanical properties, the influence of surface finish on fatigue, and the hot-cracking sensitivity of austenitic steel welds. Structural changes occurring at elevated temperatures have received considerable attention, with particular interest centred on sigma formation. The mechanical properties of stainless steels at high temperatures have been the subject of several reports, and there has been further study of corrosion by vanadium and sodium compounds. Improved methods of producing stainless steels have been reported, and the effects of various fabricating operations, on the properties of the steels, have been studied. A number of new applications have been notified.

Uses of Stainless Steel in the Chemical Industry

C. P. DILLON: 'Use of Stainless Steel to Combat Corrosion in the Chemical Industry.'
Corrosion, 1957, vol. 13, Sept., pp. 124, 125, 128, 130, 132, 134, 136–8.
Reprint of first part of paper presented to the Niagara Section of the National Association of Corrosion Engineers, May, 1956.

As an introduction to his general review of the resistance of stainless steels to corrosives encountered in the chemical industry, the author briefly discusses the factors which contribute to the outstanding corrosion-resistance of such steels. Various theories advanced to explain the mechanism of passivity are briefly noted and reference is made, in general terms, to conditions which can cause corrosion. Special attention is then drawn to the importance of galvanic relationships in promoting or inhibiting activity of stainless steels.

The general concept that stainless steels are passive under oxidizing conditions and active under reducing conditions is discussed, and examples are given of conditions in which oxidizing agents are not beneficial.

In considering the suitability of specific types of steel for individual applications in the chemical industry, the author emphasizes that the specifications which cover such steels and their applications are of fundamental importance. He develops this theme by reference to a typical A.S.T.M. specification and states that adaptation of the environment to assist satisfactory performance of the steels is more effective than minor modifications in the materials.

It is urged that a major difficulty arises from a misunderstanding of the significance of results obtained by standard tests for intergranular corrosion-resistance. These tests are arbitrary and since they are made in media which, from the point of view of intergranular attack, are the most severe known, the results obtained by them do not necessarily provide an accurate forecast of the resistance of stainless steels in service involving contact with corrosives of other types. The purpose and characteristics of the most commonly used intergranular-corrosion tests are critically discussed (Huey boiling-nitric acid, Strauss acidified-copper-sulphate, and electrolytic oxalic-acid-etch techniques).

In discussion of quality-control tests for welded structures, reference is made to a specification which operates at the plant with which the author is connected (Union Carbide Chemicals Corporation). This permits the use of welded stainless-steel condenser tubing if, after welding, it is drawn to 35 per cent. reduction and annealed. Such tubing can be used in place of the more expensive seamless tubes which are so often preferred. The reduction and annealing works out the weld to a condition in which it is virtually indistinguishable from a wrought material of similar composition, and has been found in service, to have corrosion-resistance equal to that of the parent metal. This example is advanced in support of the plea for modification and more intelligent interpretation of specifications, in the interests of economy.

High-temperature uses of the stainless steels are excluded from the survey, but attention is directed to the importance of such materials in applications involving exposure to sub-zero temperatures. Particular emphasis is laid on the importance of weld properties as a criterion of the usefulness of the steels in these conditions.

Although the full range of applications of the austenitic stainless is too wide a subject to be dealt with as a section of one paper, the author makes a summarized survey of some well-established information on the behaviour of such materials in plant handling acetic and sulphuric acids, caustic media, sulphurous acid, phosphoric acid and cooling water.

This first part of the paper concludes with a brief note on the suitability of stainless steels for use in chemical- and food-handling equipment and other plant in which avoidance of contamination of refined products is of primary importance.

Materials for Ducts and Hoods of Exhaust Systems

'Corrosion of Ducts and Hoods in Exhaust Systems.' *Air Conditioning, Heating and Ventilation*, 1957, vol. 54, Apr., pp. 83–4.

Tabular summary, compiled by the Division of Industrial Hygiene, New York State Department of Labour. The materials are classified in five ratings, varying from 'excellent' (over 5 years' service) to 'poor' (6 months' life): the designations have been assigned on information obtained by collation of field-service reports.

The conditions of exposure considered include those involved in ducts and hoods in chromium-, copper- and nickel-plating plant, and in installations in which the following types of corrodent are handled: hydrochloric, hydrofluoric, nitric, oxalic, sulphuric and mixed acids; alkaline cleaning solutions; tanning, dyeing, and bleaching media; boiling water and steam; decarbonizing agents; degreasing compounds; fumes from enamelling and lacquering operations. The construction (duct and hood) materials of which some assessment is made include metallic materials, wood, rubbers, resins, cement and asphalt. Stainless steel, Monel, lead, aluminium, unalloyed steel, and iron are among the materials for which information is given.

Nickel-Chromium-Boron Alloys for Brazing Titanium-containing Alloys

G. AGGEN, R. A. LONG and E. E. REYNOLDS: 'Ni-Cr-B Brazing of a High-Temperature Alloy.' *Welding Jnl.*, 1957, vol. 36, Aug., pp. 366S–72S.

The use of brazing for joining of jet-engine components which will operate at elevated temperatures has become increasingly significant during the past few years. Factors which have favoured the use of this method have been the development of furnaces capable of protecting the surfaces which are to be brazed, and the advent of brazing alloys which have good strength and oxidation-resistance at elevated temperatures.

All the iron-, nickel- and cobalt-base alloys commonly used in high-temperature applications contain 10–20 per cent. chromium, and in some of them 1–3 per cent. of oxidizable elements e.g., aluminium and titanium are also present. Such elements seriously interfere with the production of consistently sound brazed joints, presumably due to formation, at the surfaces of oxides which inhibit uniform wetting by the brazing alloys. The obstacle of oxidation has been partially overcome by the use of atmospheres of very dry hydrogen (dew points of $-60°F.:-51°C.$ or lower), but although such atmospheres usually afford adequate protection for alloys containing only chromium or chromium+nickel, they are not sufficiently protective for materials containing substantial amounts of titanium and aluminium, and for such types it is usually necessary to plate the surfaces which are to be brazed with iron or nickel. Brazing in vacuum is also being studied as an alternative method of protection, but it appears likely that very high vacuum will be required for successful brazing of alloys containing appreciable amounts of aluminium and titanium.

A series of brazing alloys which show promising elevated-temperature properties are of nickel base, and contain a substantial amount of chromium, together with small percentages of boron or silicon, which substantially lower the melting-temperature ranges of the alloys. Such alloys usually require temperatures of about 2100°F. (1150°C.) to ensure satisfactory flow.

This report deals with brazing experiments carried

out on steel of the following composition: carbon 0·03, silicon 0·5, manganese 1·3, chromium 14·7, nickel 25·5, molybdenum 1·3, titanium 2·1, aluminium 0·2, vanadium 0·3, per cent., iron balance. This material, designated A-286, conforms to S.A.E./A.M.S. Specification 5735.

The brazing material used (S.A.E./A.M.S. 4775) contained carbon 1, silicon 4, chromium 17, iron 4, boron 4, nickel 70, per cent. The solidus temperature of this alloy is about 1850°F. (1010°C.) and its liquidus lies at about 1950°F. (1065°C.).

The purpose of the investigation was threefold:

(1) To determine the effects of the heat-treatment cycle used in brazing, on the properties of the alloy.

(2) To determine the effects of alloying with the brazing alloy, on the properties and microstructure of the base metal. (For this purpose brazing-alloy powder was applied to the surfaces of fully machined blanks, which were then passed through a typical brazing cycle.)

(3) To obtain information on the strength of brazed joints under tensile and shear stresses.

The paper includes detailed descriptions of the brazing furnace and the brazing cycles used, and of the optimum procedure developed.* The quality of the brazed joints was evaluated by metallographic examination and mechanical tests, including smooth- and notched-bar rupture tests at 1200°F. (650°C.) and short-time tensile tests at room temperature and at 1200° and 1300°F. (650° and 705°C.).

The results of the investigation indicate that the brazing cycle somewhat impairs the properties of the high-temperature material at 1200°F. (650°C.) but that these properties can be largely recovered by application of correct post-brazing heat-treatment. Microstructural changes introduced at the surfaces of the base metal by the brazing alloy are shown to result in improved elevated-temperature properties. The strengths of the brazed joints obtained by the procedure recommended* were satisfactory, although not so high as those of the parent A-286 alloy.

**The method developed* is based on the tentative theory that the reactive elements such as titanium and aluminium can be preferentially oxidized at the surfaces of the alloy and that the oxidized layer can then be removed by chemical action, resulting in a fresh surface which has wetting characteristics suitable for subsequent brazing. In the successful experiments reported, the preliminary oxidation treatment was carried out in a continuous belt furnace with a hydrogen atmosphere of −40°F. (−40°C.) dew point. This treatment caused formation of a selective thin dark oxidized coating, which was subsequently removed by treatment in nitric-hydrofluoric-acid mixture. Brazing was then carried out in the same furnace, using dry hydrogen of −80°F. (−62°C.) dew point and a rapid brazing cycle. By this method the parts were well wetted by the brazing alloy and the colour of the parent material remained bright. Repeat tests consistently gave satisfactory results.

Filler Rods and Wires for Gas Welding of Nickel-containing Steels

BRIT. STANDARDS INSTN.: 'Filler Rods and Wires for Gas Welding.'
B.S. 1453: 1957; 25 pp. Price 6/-.

The standard relates to a series of ferrous and non-ferrous filler rods and wires for gas welding.

Part 1 contains general clauses applicable to all types of gas-welding material covered by the schedule. Part 2 embodies the compositional requirements and applications for individual types of filler rods and wires, as shown below.

Mild Steel of two grades.
Medium-tensile (manganese) steel.
3 per cent. nickel steel.
Wear-resisting alloy steel (chromium-manganese steel).
Carbon-molybdenum steel.
Chromium-nickel corrosion-resisting steel, niobium-stabilized (18-8 type).
25-12 Chromium-nickel heat-resisting steel (normal grade and niobium-stabilized).
25-20 Chromium-nickel heat-resisting steel (normal grade and niobium-stabilized).
Molybdenum-bearing chromium-nickel corrosion-resisting steel (normal grade and niobium-stabilized).
High-silicon cast iron.
Cast iron of lower silicon content.
Nickel cast iron.
Copper.
Brass.
Manganese bronze.
Medium nickel bronze (high-tensile nickel brass): Ni 8-11 per cent.
High-nickel bronze (high-tensile nickel brass): Ni 14-16 per cent.
Magnesium-aluminium and magnesium-maganese alloys.
Aluminium and aluminium alloys (10 varieties).

Appendices to the specification cover:

Conditions for carrying out the intercrystalline-corrosion test.
Notes on selection of filler rods and wires for welding of aluminium-magnesium and aluminium-magnesium-silicon alloys.

Corrigenda

Nickel Bulletin, July-Aug. 1957, p. 121.
Left-hand column, beginning of last paragraph.
For 'electrochemical' *read* 'electromechanical'.

ibid., Sept., 1957, p. 165, right-hand column.
'S.G. Iron in Marine Applications'
after 'A. G. Arnold', *add* 'and B. Todd'.

Binders bearing the date 195- and suitable for 1957 and 1958 Nickel Bulletins are now available. We shall be pleased to send one free of charge.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

INDEXES TO ITEMS IN

NICKEL BULLETIN, 1957, VOLUME 30

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SUBJECT INDEX TO VOLUME 30

The Index comprises a consolidated list of titles of abstracts, compiled from the sectional lists of the individual issues.

Within the Sections normally used (**GENERAL, NICKEL, ELECTRODEPOSITION,** etc.), the items are broadly classified in appropriate sub-sections, within which they are, in most cases, entered in the order of their appearance in the Bulletin. The only exceptions to such order are (1) the grouping of the page numbers of serial items and of items of very closely related subject matter, and (2) the alphabetical order used in the **'GENERAL'** Section. The Leading Article referred to below, although listed separately, is shown also in the appropriate sections, where it is differentiated from the abstracts by an asterisk at the beginning of the entry.

A list of **Trade-Named Materials and Processes** referred to in this volume of the Bulletin appears on p. 252.

LEADING ARTICLE

EFFECTS OF IMPURITIES IN NICKEL-PLATING SOLUTIONS AND METHODS OF PURIFICATION 152-155

GENERAL

(See also **General** and **Testing** Sub-Sections of other Sections)

The items which are listed in this Section have been entered also in other appropriate sections of the Contents List.

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